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AMAZING VEHICLES

A LOOK INSIDE SOME OF THE WORLD'S MOST INCREDIBLE MACHINES

Digital Edition

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FIRST EDITION

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From supersonic jets and rocket-powered planes to massive ocean liners and underwater cars, this book is packed with the most incredible machines to roam the planet. Discover how a new generation of luxury airliners, solar planes and new wave ships are changing the way we travel and explore the world. Learn how modern combat has been revolutionised by some truly astonishing vehicles, and delve deep into the history of engineering with the first cars and iconic planes that shaped today's transport. If you love power, speed and ground-breaking technology, engineering and aerodynamics, then you'll love How It Works Book of Amazing Vehicles.

FUTURE

HOW IT WORKS BOOK OF AMAZING VEHICLES

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Part of the HOW IT WORKS bookazine series

HOW IT WORKS

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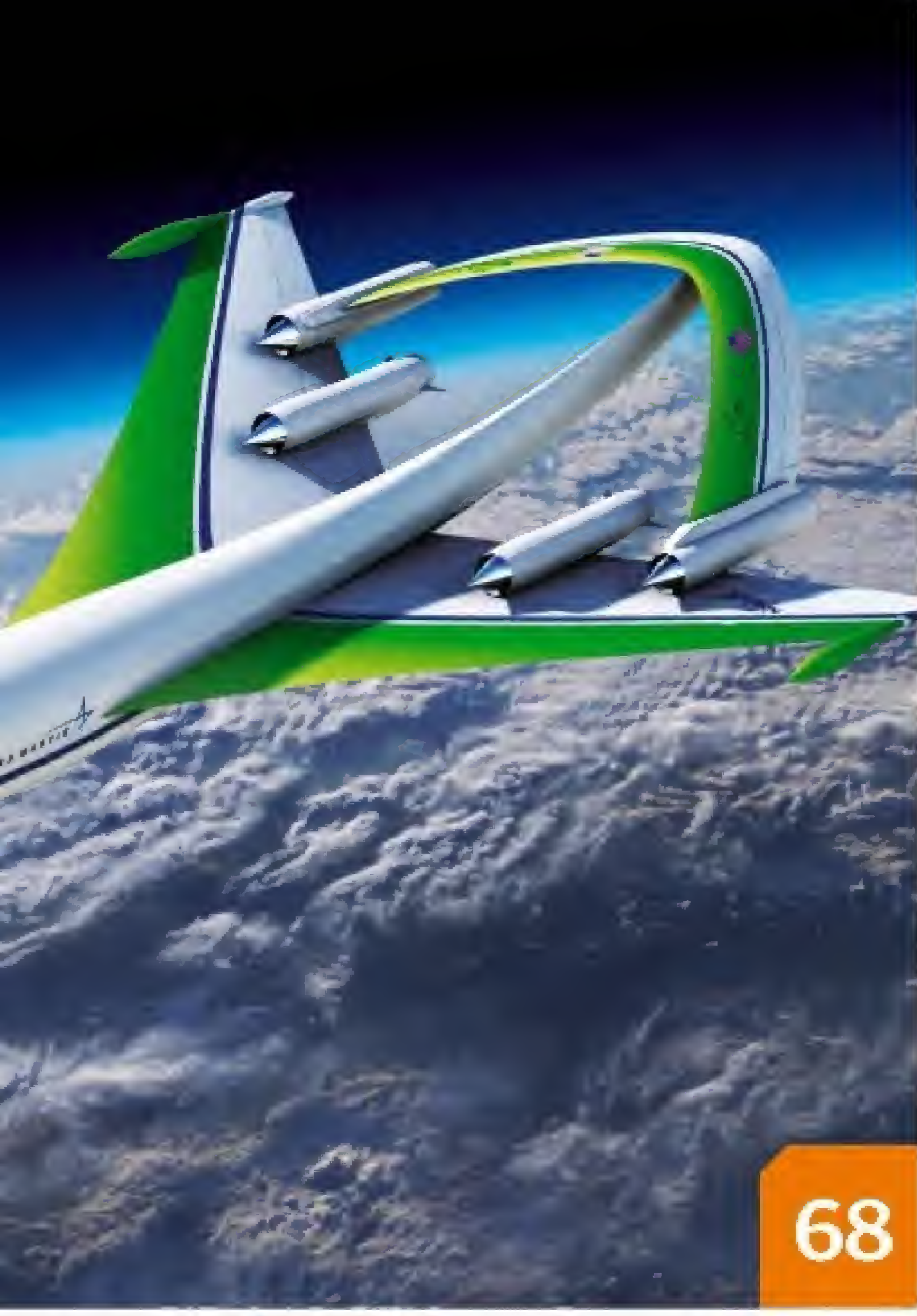

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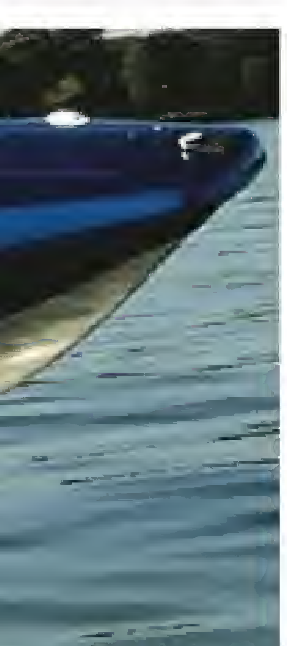

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WORLD'S FASTEST VEHICLES

Blink and you'll miss these speed machines, but what high-octane engineering is under the hood?

In 1906, on the packed sands of Ormond Beach in Florida, USA, mankind's obsession with speed shifted into an entirely new gear. Powered by kerosene-burning steam engines, the world's first racecars broke the 160-kilometre (100-mile)-per-hour mark, igniting a race for the record books – one that roars on today. In 2014, the Bloodhound SSC hopes to speed past the 1,600-kilometre (1,000-mile)-per-hour barrier, smashing the current land-speed record by nearly 400 kilometres (250 miles) per hour and reaching a velocity that could outrun a Magnum .357 bullet. The quest to build the world's fastest vehicles on land, air and sea is equal parts physics, robust materials and, to a certain extent, abject lunacy. Hundreds have lost their lives piloting home-made rocket boats and blasting experimental aircraft to the edge of space. But as long as there's a new milestone to reach – speed of sound, Mach 20, perhaps even the speed of light – our brightest scientific minds and wildest daredevils will be willing to take on the challenge.

F1 engine
Custom-built by Cosworth, this 559kW (750hp) engine will pump 800 litres of high-test peroxide oxidiser to the hybrid rocket.

Jet-powered cars

A sonic boom echoed off the stone cliffs of the Black Rock Desert in Nevada, USA, as the British-made Thrust SSC became the first land vehicle to break the sound barrier back in 1997. To qualify for a land-speed record of 1,149 kilometres (763 miles) per hour, the car needed to have four wheels and be under complete control of the driver. It also needed to withstand air pressure upwards of ten tons per square metre. To improve stability, the rocket-shaped car was equipped with twin Rolls-Royce Spey jet engines, one on each side. Each engine produced 89 kilonewtons (20,000 pounds-force) of thrust, roughly equal to 145 Formula One cars. The next-generation Bloodhound SSC – pictured here – aims to exceed 1,600 kilometres per hour (1,000 miles per hour) in 2014 with a Eurofighter Typhoon jet engine and a hybrid rocket strapped to its sleek carbon-fibre and titanium cage frame. The Bloodhound will rocket from zero to 1,690 kilometres (1,050 miles) per hour in just 40 seconds on 900-millimetre (2.9-foot) aluminium alloy wheels.

The bumps in the road

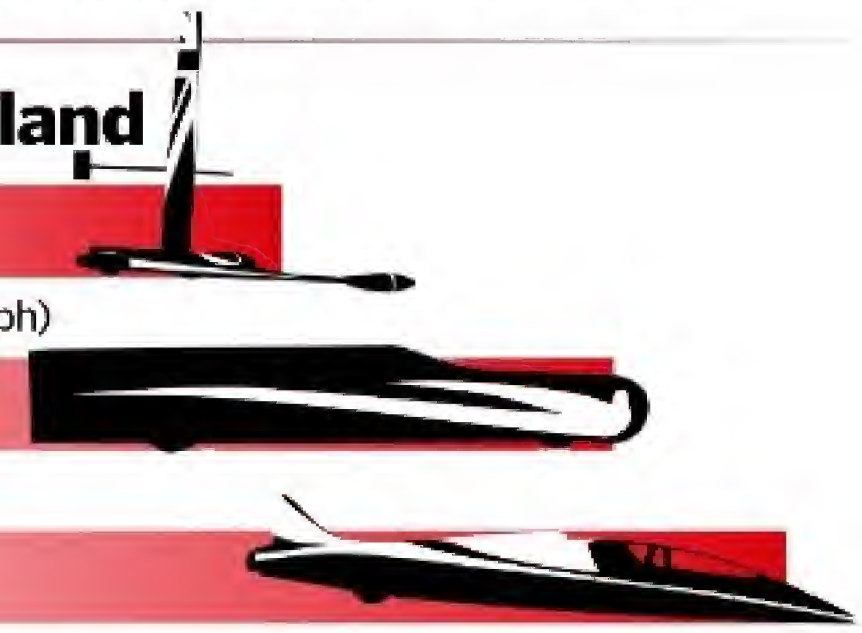
Drag is one of the greatest engineering challenges to designing a supersonic land vehicle capable of breaking speed records. Even low-flying fighter jets have only reached 1,600 kilometres (994 miles) per hour and that's without the friction of wheels on the ground. Air is much denser at ground level than at high altitude, meaning cars have to be ultra-aerodynamic (hence the rocket shape) and produce insane amounts of thrust. The Aussie Invader 5R, one of the land-speed contenders, solved this problem by sitting its driver atop what is essentially a 16-metre (52-foot) rocket engine capable of producing 276 kilonewtons (62,000 pounds) of thrust. Wheels are another huge challenge, as they need to rotate at unimaginable speeds while sticking firmly to the ground. The solution is tireless wheels machined from either titanium or aluminium, which boast a very high strength-to-weight ratio. The Aussie Invader's aluminium wheels are built for 10,000 rotations per minute. When the Thrust SSC broke the sound barrier, the shockwave 'fluidised' the sandy soil beneath the vehicle, making it difficult to steer. Next-gen rocket cars are using computer modelling to muffle those vibrations.

Some have contested the Venom GT is faster than the Veyron Super Sport overall but this is yet to be confirmed

Speed vs acceleration

In January 2013, a Hennessey Venom GT ripped down an airport runway in Texas to break the world acceleration record: 0-300km/h (186mph) in 13.63s. Acceleration is not the same as speed. Acceleration is a product of the V8 engine's torque (force) divided by the Venom GT's mass (ie a = f/m). The Venom accelerates so quickly because its lightweight 1,244kg (2,743lb) frame is cranked by 160kg/m (1,155lb/ft) of torque. The heavier Bugatti Super Sport loses to the Venom GT in a sprint, but can hold the road at higher maximum speeds.

Other speed demons… on land



Fastest wind-powered car

Ecotricity Greenbird, 203km/h (126mph)

Fastest motorcycle

Ack Attack, 606km/h (377mph)

Fastest piston engine car

Speed Demon, 743.5km/h (462mph)

WORLD'S FASTEST PRODUCTION CAR

The first thing you notice about the Bugatti Veyron Super Sport isn't its Lamborghini good looks, but its Tyrannosaurus roar. The Bugatti's 16-cylinder engine delivers over 1,200 horsepower, ripping from 0-100 kilometres (60 miles) per hour in a staggering 2.5 seconds. The only thing preventing the Bugatti from pushing over 431 kilometres (268 miles) per hour is the rubber tyres, which would tear apart from the force. And at £26,000 ($42,000) for four tyres, it's better to be safe than sorry! To deliver that much power, the eight-litre engine gulps down fuel; at full pelt, the Bugatti would drain its entire tank in about 12 minutes.

WORLD'S FASTEST MANNED AIRCRAFT

The fastest-ever manned aeroplane made its record-setting flight 47 years ago. In the early days of the Space Race, the X-15 was designed to test the limits of aeronautical engineering at the edge of space. Built like a short-winged fighter jet, the X-15 packed a rocket under its hood. To fly, it would hitch a ride on a massive B-52 up to 13,700 metres (45,000 feet). Dropped from the bomber, the X-15 lit its liquid propellant rocket capable of 500,000 horsepower. The X-15 only carried enough fuel for 83 seconds of powered flight – but it was enough to rocket its pilots into the record books.

NORTH AMERICAN X-15

Top speed
7,274km/h (4,520 mph)

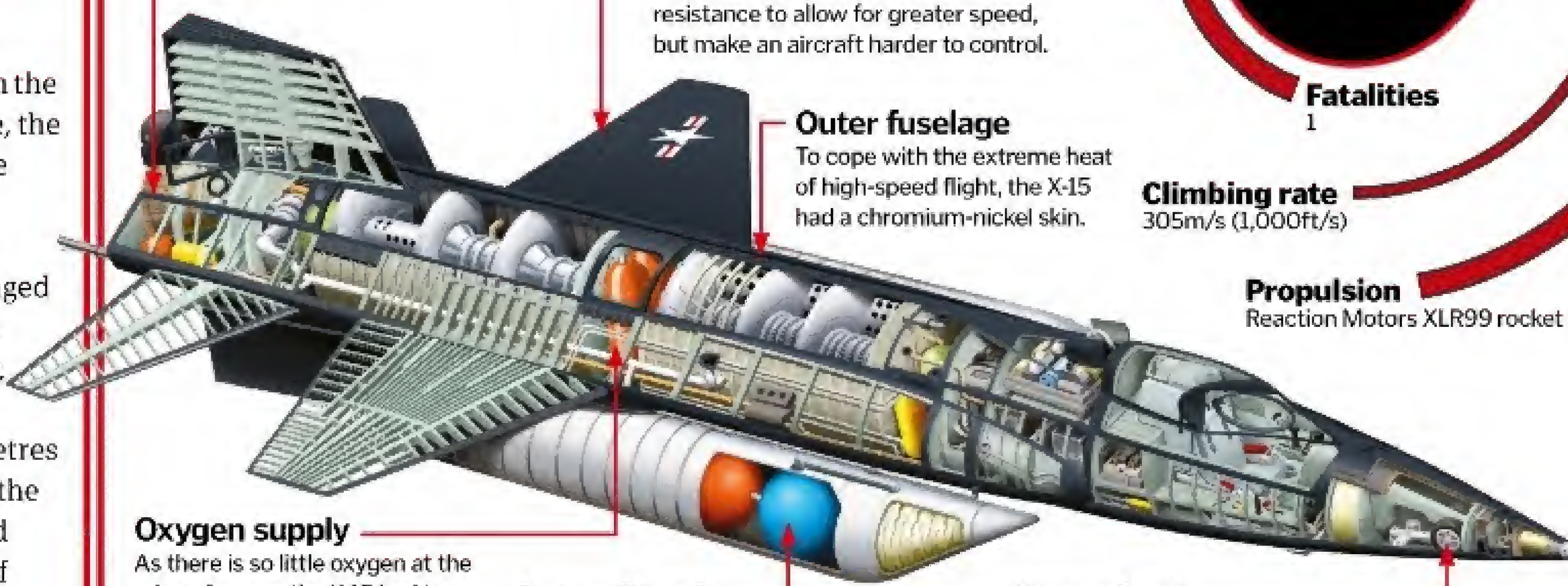
Top altitude
107,960m (354,200ft)

Mission flights
199

Fatalities
1

Climbing rate
305m/s (1,000ft/s)

Propulsion
Reaction Motors XLR99 rocket



Rocket engine
The XLR99 engine was throttled, which meant thrust could be adjusted from half to full.

Short wings
Stubby wings create less air resistance to allow for greater speed, but make an aircraft harder to control.

Outer fuselage
To cope with the extreme heat of high-speed flight, the X-15 had a chromium-nickel skin.

Oxygen supply
As there is so little oxygen at the edge of space, the X-15 had to take its own for burning fuel.

Drop-off tanks
When the second iteration of the X-15 was damaged on landing, the fuel tanks were redesigned to fall away.

Nose wheel
The front wheel could not be steered so the X-15 had to land on a lake bed rather than a runway.

Aerodynamic challenges

The engineering challenges for high-speed aircraft are surprisingly similar to building the world's fastest cars. Drag is still public enemy number one. As an aircraft approaches the speed of sound, the gas flowing around the plane grows more viscous, 'sticking' to the surface and altering the aerodynamic shape of the craft. Any friction with that high-velocity stream of gases will cause bone-rattling turbulence, incredible heat and shockwaves. To achieve the best aerodynamic profile, supersonic planes have swept-back wings that stay safely inside the cone of a supersonic shockwave. The F-14 fighter jet can pull its wings in tight for maximum speed and stretch them out for greater control at lower speeds. Supersonic craft are also made from lightweight materials like aluminium to further reduce drag.

Of course, you'll never reach supersonic speeds without serious engine power. X-1, the first plane to break the sound barrier in 1947, was propelled by a rocket, but modern turbojet engines like the Concorde's four Rolls-Royce turbofans, are also capable of supersonic flight. Hypersonic flight – ie greater than Mach 5 – has its own unique set of challenges because gas molecules begin to break apart and create multiple overlapping shockwaves. Experimental hypersonic designs such as the Falcon HTV look more like wingless sci-fi vehicles than traditional planes.

The HTV-2 test flight lasted about nine minutes, before heat damage forced the mission to be terminated

Other speed demons... in the air

Fastest space plane
Virgin Galactic's SpaceShipTwo, 1,752km/h (1,089mph)

Fastest jet aircraft
Blackbird SR-71, 3,185km/h+ (1,979mph+)

Fastest unmanned plane
Falcon HTV-2, 20,921km/h (13,000mph)

Slicing through the water

Just like air and land, the greatest obstacle to record-breaking speeds on the water is drag. Water is about 1,000 times denser than air, so the best way to increase speed on water, ironically, is to make as little contact as possible with the water itself. If you watch a speedboat race, most of the boat lifts out of the water at top speeds – an aerodynamic engineering feat called 'foiling'. The twin hulls of America's Cup catamarans lift entirely out of the water, riding only on razor-thin hydrofoil blades. The catamaran design increases overall stability without the necessity of a single hull sitting deep in the water.

Other speed demons... in water

Fastest warship

US Navy Independence, 83km/h (52mph)

Fastest hovercraft

Universal UH19P: Jenny II, 137.4km/h (85.4mph)

Fastest hydrofoil

US Navy Fresh-1, 155.6km/h (96.7mph)

Spirit of Australia

Since childhood, Australian speedboater Ken Warby dreamed of breaking the world speed record. His hero, British daredevil Donald Campbell, died trying. In the Seventies, without a sponsor, Warby built the Spirit of Australia in his Sydney backyard, buying three clunky jet engines in a RAAF surplus auction. Warby used years of speedboat experience to draft the three-point hydroplane design, in which only three parts of the underside of the boat touch the water at high speeds, greatly reducing drag. With help from a university wind tunnel and the RAAF, Warby reached a death-defying 511.1km/h (317.6mph) in 1978 – a record that still stands to this day.

WORLD'S FASTEST PASSENGER FERRY

It's one thing to see a tiny speedboat race across the ocean surface, but it's downright mind-blowing to watch a 99-metre (295-foot) ferry hit speeds of more than 50 knots (93 kilometres/58 miles per hour) while carrying up to 1,000 passengers and 150 cars. The Francisco is Australian shipmaker Incat's latest breakthrough; a twin-hulled catamaran powered by two massive turbine engines running on liquefied natural gas (LNG). The turbines force water through two enormous waterjets that propel and steer the craft, which cuts through the waves like a warm knife through butter. The Francisco will ferry passengers in style and speed from Buenos Aires in Argentina, to Montevideo in Uruguay.

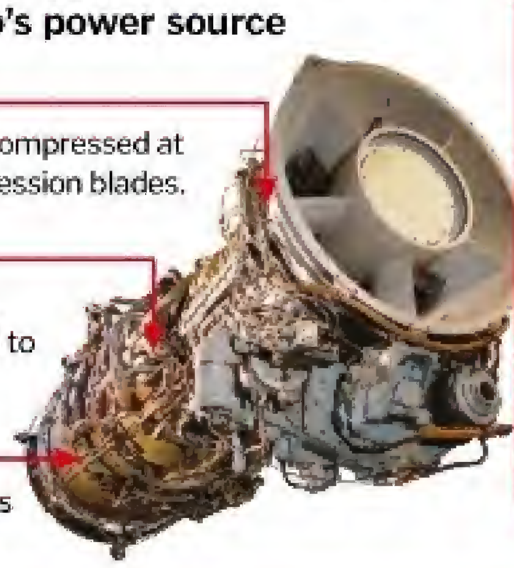
LM2500 marine gas turbine

A closer look at the Francisco's power source

Compressor
Rotating fan blades draw in air that's compressed at an 18:1 ratio through a series of compression blades.

Combustor
Liquid natural gas is injected into the compressed air chamber and ignited to release tremendous energy.

Turbine
The flow of hot exhaust spins a series of turbines connected to a waterjet.



On the clock: London to New York

How long would it take the world's quickest vehicles to hop across the Atlantic at maximum speed (if there was a bridge)?

Scorpion FV101 tank
76.8 hours

VeloX3 bicycle
41.7 hours

Bugatti Veyron Super Sport
12.7 hours

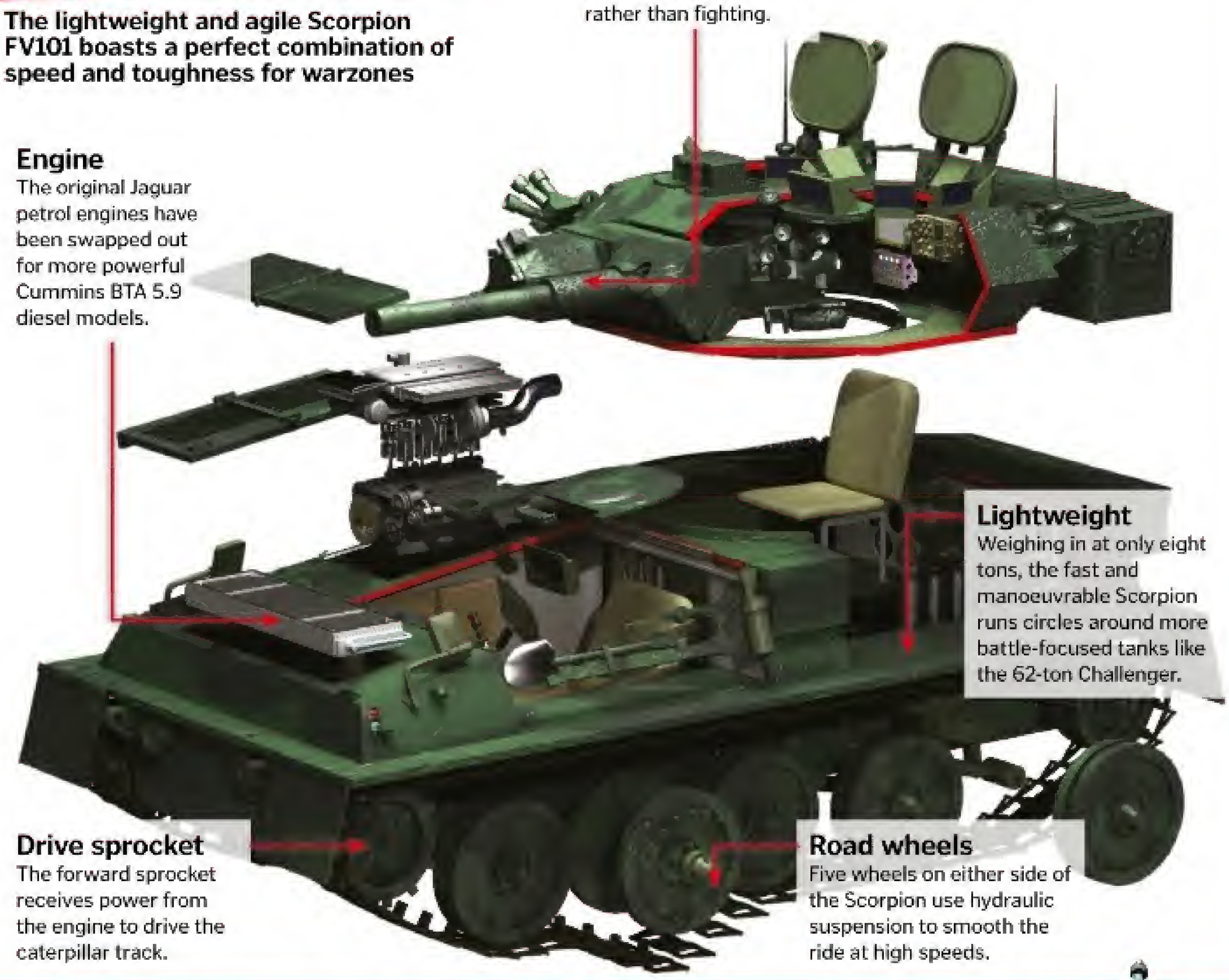
Speed on the rails

The future of high-speed trains is without a doubt magnetic. The principle of magnetic levitation (maglev) allows trains to reduce drag by floating on a one to ten-centimetre (0.4 to four-inch) cushion of air created by opposing electromagnetic fields in the track and car. The Shanghai Maglev Train in China became the first commercial maglev in 2003 and still holds the operational speed record for a commercial train: 431km/h (268mph). However, Japan is developing its own maglev line between Tokyo and Nagoya, with trials hitting the 500km/h (310mph) mark. Tech entrepreneur Elon Musk (founder of SpaceX) plans to take maglev to the next level. His Hyperloop design propels train cars through a sealed, low-pressure tube on cushions of air at speeds approaching 1,300km/h (800mph). Today, conventional high-speed lines in Spain, France, Italy, South Korea and elsewhere reach speeds exceeding 300km/h (186mph), using a combination of streamlined aerodynamics, lightweight plastics and electric-powered locomotives.

The new L0 maglev train being tested in Japan has already clocked 500km/h (311mph)

FASTEST VEHICLE ON TRACKS

The lightweight and agile Scorpion FV101 boasts a perfect combination of speed and toughness for warzones



Spirit of Australia
10.9 hours

Thrust SSC rocket car
4.5 hours

X-15 rocket plane
46 minutes

Fast and curious...

1 Milk float
By swapping the milk delivery truck's electric motor with a V8 engine, British Touring Car Championship driver Tom Onslow-Cole reached 124.8km/h (77.5mph) in the not-so-aerodynamic buggy as part of the eBay Motors Mechanics Challenge.

2 Lawnmower
Honda UK's 'Mean Mower' goes from 0-97km/h (60mph) in four seconds and claims to reach top speeds (on the track, not the lawn) of 209km/h (130mph). Makes quick work of cutting the grass, but the 1,000cc motorcycle engine might bother the neighbours!

3 Police fleet
Only in Dubai... In 2013, the city of unrepentant excess made some additions to its public safety patrol: a £275,000 ($450,000) Lamborghini Aventador and a Ferrari FF. Criminals have no chance of making a getaway!

4 Bicycle
The VeloX3, built by a team of Dutch university students, looks like an elongated egg. The recumbent bicycle is covered in a hyper-aerodynamic shell that enabled it to reach record speeds of 133.8km/h (83.1mph) in 2013.

5 Skateboard
Mischo Erban is king of the daredevil maniacs who practise the competitive sport of downhill skateboarding. Erban set a new world record in 2012, reaching 130km/h (80.7mph) on a mountain road in Québec, Canada.

HOW IT WORKS LAND

High-speed wonders and amazing machines

"Take a look at the most notable and advanced vehicles"

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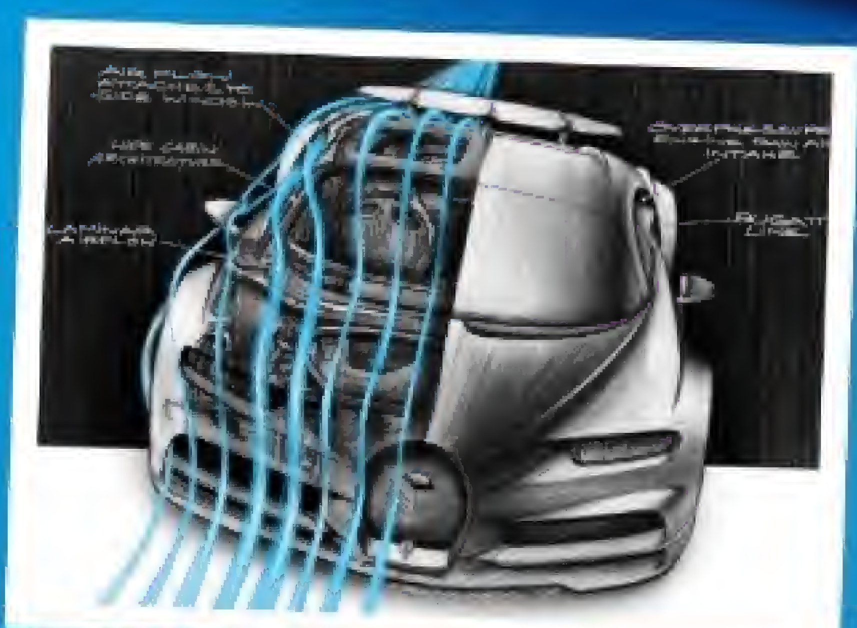
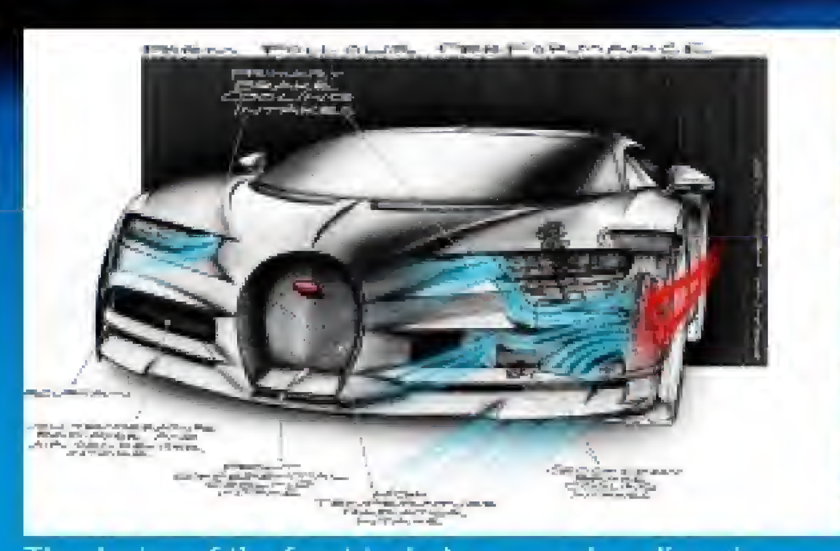
»HOW TO BUILD A SUPER

DISCOVER HOW BUGATTI MADE THE CHIRON THE FASTEST PRODUCTION SPORTS CAR ON THE ROAD

Contrary to our fanciful artwork, no robots are used to build the Bugatti Chiron



The cabin design is constrained by having the gearbox in front of the engine



The design of the front includes several cooling air intakes while maintaining Bugatti's distinctive styling

CAR

What is a supercar? Ask automotive experts that question and they are all likely to give you a different answer. Take one look at the Bugatti Chiron, though, and you'll have absolutely no doubt that it deserves the distinction.

With a £2 million ($2.5 million) price tag, the Chiron conveys not only affluence but also an appreciation for exceptionally high standards. Alongside Bugatti, most well known manufacturers of racing cars, including Ferrari, Porsche, Lotus and Lamborghini, have produced road vehicles that are a cut above conventional sports cars. Yet none of these currently matches Bugatti as the foremost creator of high performance automobiles.

Bugatti has a long history of creating exceptional motor vehicles. The company was founded in 1909 by Italian-born Ettore Bugatti. He set up a factory in Molsheim, France, which was then under German control. After the Second World War the company experienced mixed fortunes for many years, including bankruptcy. The brand entered a new era in 1998, however, when it was bought by Volkswagen. The new owner immediately set about re-establishing Bugatti's reputation by starting a project to design and build the ultimate supercar – a vehicle that would push the boundaries of automotive luxury and engineering.

The result was the Bugatti Veyron. Entering production in 2005, the Veyron boasted 1,000 horsepower and could reach 400 kilometres per hour. The

The Chiron isn't just powerful – anodised aluminium trim adds class to its appearance

design combined unique styling with a host of mechanical innovations that were necessary for the car to reach and maintain its top speed safely. At the core of these was a unique 16-cylinder engine that earned Bugatti a world record in 2010 when a Super Sport edition of the Veyron reached a speed of 431 kilometres per hour.

The Veyron still holds the Guinness World Record as the fastest production car ever built. Even so, Bugatti hasn't rested on its laurels. The Chiron is a direct descendent of the Veyron, reflecting the belief among Bugatti's engineers that they could build a street-legal car that goes even faster.

CREATING A BIGGER BEAST

With the Veyron, the objective had been to design a car that could be driven at high speeds on the track and be equally at home on the high street. That ambition continued with the Chiron, but with the added criterion that its engine performance had to be 25 per cent better than the Veyron's. To achieve this, Bugatti's integrated team of designers and engineers went back to the drawing board, revamping the car from the inside out. Design concepts were rendered as 3D models in a computer and a full-scale clay version of the car was built to give the team a feel for what the finished product would look like.

One thing Bugatti didn't reinvent, though, was the Veyron's incredible 8.0-litre W16 engine. Nonetheless, it has been updated in significant ways. The engine is assembled from handcrafted components made from strong but lightweight titanium alloys and carbon fiber. Over the period of about a week each engine is individually put together in a clean room to prevent grit from getting into the moving parts. The Chiron engine has 16 cylinders, like the Veyron's, but its four proprietary turbochargers are now double-powered. The specially designed clutch system, which has two transmissions, is also stronger than the Veyron's. This feature allows the Chiron to accelerate to its electronically-limited top speed of over 420 kilometres per hour

Inside the Atelier

Discover Bugatti's Molsheim workshop, a facility as amazing as the car that's built there

Ready and waiting
The front end of the transmission assembly is readied in position to connect to the drivetrain.

The EC nutrunner alerts the operator when each nut is at the required torque

Each Chiron is assembled by hand; no robots are used at any stage of production

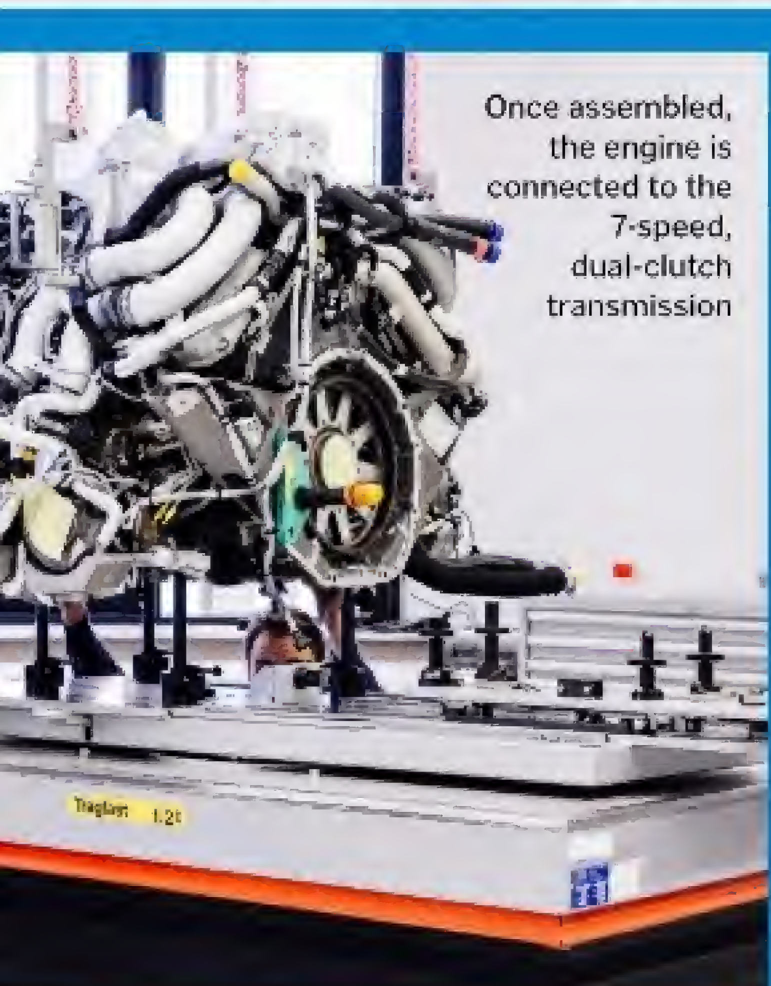
"'Form follows performance' is Bugatti's motto for this car"

Assembly stations are kept in pristine condition, with no oily rags in sight

Veyron vs Chiron

The Bugatti Veyron is still an amazing vehicle, but expectations have risen in the decade since it went into production. Hence, Bugatti has surged ahead with the Chiron. This new car can produce 1,480 horsepower – almost half as much again as the original Veyron – and a higher top speed thanks to exploitation of physics and advances across the board in materials and mechanics. The most prominent sign of this is the Chiron's distinctive side air intakes, which keep down the temperature of the incredible engine by making air resistance work in the car's favour. Internal improvements, meanwhile, include staggered triggering of the more powerful turbochargers to boost engine efficiency, the use of lighter materials in the engine, frame and panels, and new disc brakes that are larger in diameter and thicker than the Veyron's. Together, these allow the Chiron to race past its record-setting predecessor.

Fierce competition pushed Bugatti's engineers to exceed their achievements with the Veyron



Once assembled, the engine is connected to the 7-speed, dual-clutch transmission

The rear end of the car houses the massive engine and the powertrain

uninterrupted by gear changes. Essentially, when the driver shifts gears, the second transmission readies the next gear so that it engages as soon as it is needed.

To ensure the ambitious targets for the Chiron's engine wouldn't push it too hard, Bugatti's engineers tested the power output of a prototype using a dynamometer. The story goes that the engine survived but blew up the test apparatus, so a new dyno had to be specially built to complete the testing. Still, there is more to squeezing every ounce of performance out of a car than just boosting the output of its engine. Among the natural forces aligned against speed are gravity and wind resistance. To keep the Chiron ahead of the competition, Bugatti's designers have had to find new ways of exploiting the laws of physics to their advantage.

With a curb weight of almost two tons, the Chiron is heavier than the average car. To compensate for this, the frame and body panels, like the engine, are made from state-of-the-art materials that are light but strong. The former is assembled from high-strength steel with every joint bolted by hand. The only electronic tool used in assembling the chassis is an EC nutrunner. This high-tech spanner records how much each bolt has been tightened to ensure consistency and saves this data in a computer. The body panels, meanwhile, are comprised of carbon fibre strengthened by a honeycomb-structured aluminium inner layer.

Just as important as the physical properties of these panels, however, is the work that some of them do when they are on the car. Once attached to the frame, laminated and painted – a process that takes several weeks – they give the Chiron it's eye-catching appearance. 'Form follows performance' is Bugatti's motto for this car, and there is nothing that better exemplifies this than the Chiron's sweeping contours, especially the striking C-shaped motif that curves around the doors on each side.

A car with an optimal aerodynamic design deflects air without causing turbulence. To find the Chiron's ideal configuration, engineers studied a scale model in a wind tunnel so that they could map the air movement around different parts of its body. What this revealed is that the Chiron's front end could be designed in such a way that the air travelling up to and around the curved windscreen is channelled into more or less straight lines, called laminar flow. This minimises turbulence and directs airflows towards the back of the car where the engine is located.

One major problem the Bugatti team faced in designing an engine powerful enough to reach 6,700 revolutions per minute is that it would overheat quickly without an effective cooling system. The Veyron needed ten radiators to keep its engine temperature down, and the challenge was even greater with the Chiron. Therefore, the engineers came up with a water circulation system that can move up to 800 litres of water per minute through the engine.

Nevertheless, water-cooling is not enough, which is why those airflows deflected from the front of the car come in handy. The C-shaped panels that project out of each side of the Chiron are actually cleverly designed air intakes that collect deflected air and channel it into the engine compartment. This air acts like a fan, picking up the excess thermal energy from the engine before being sucked out of large vents in the back of the car due to a pressure differential.

CHALLENGING PHYSICS

The trouble is that airflows aren't all good for a supercar. When acting against an object going at high speed, air can lift it off the ground. You want that if you're jetting off on holiday in a plane, but for a car driver, even the slightest loss of contact with the road compromises vehicle handling and could be very dangerous.

To address this, Bugatti's designers have taken another lesson from the Veyron and given the Chiron a computer-controlled retractable spoiler. The purpose of the spoiler is two-fold – produce enough downforce to keep the car on the road when it's going fast, and slow it down safely if the driver needs to break when they have their foot to the floor.

At low speeds the spoiler remains embedded in the back of the car. As the car accelerates tiny sensors send signals to the onboard computer, which can trigger deployment of the spoiler in a fraction of a second. When the brakes are engaged, the spoiler adapts to help the driver complete their turn. This provides resistance to

How a rolling dynamometer works

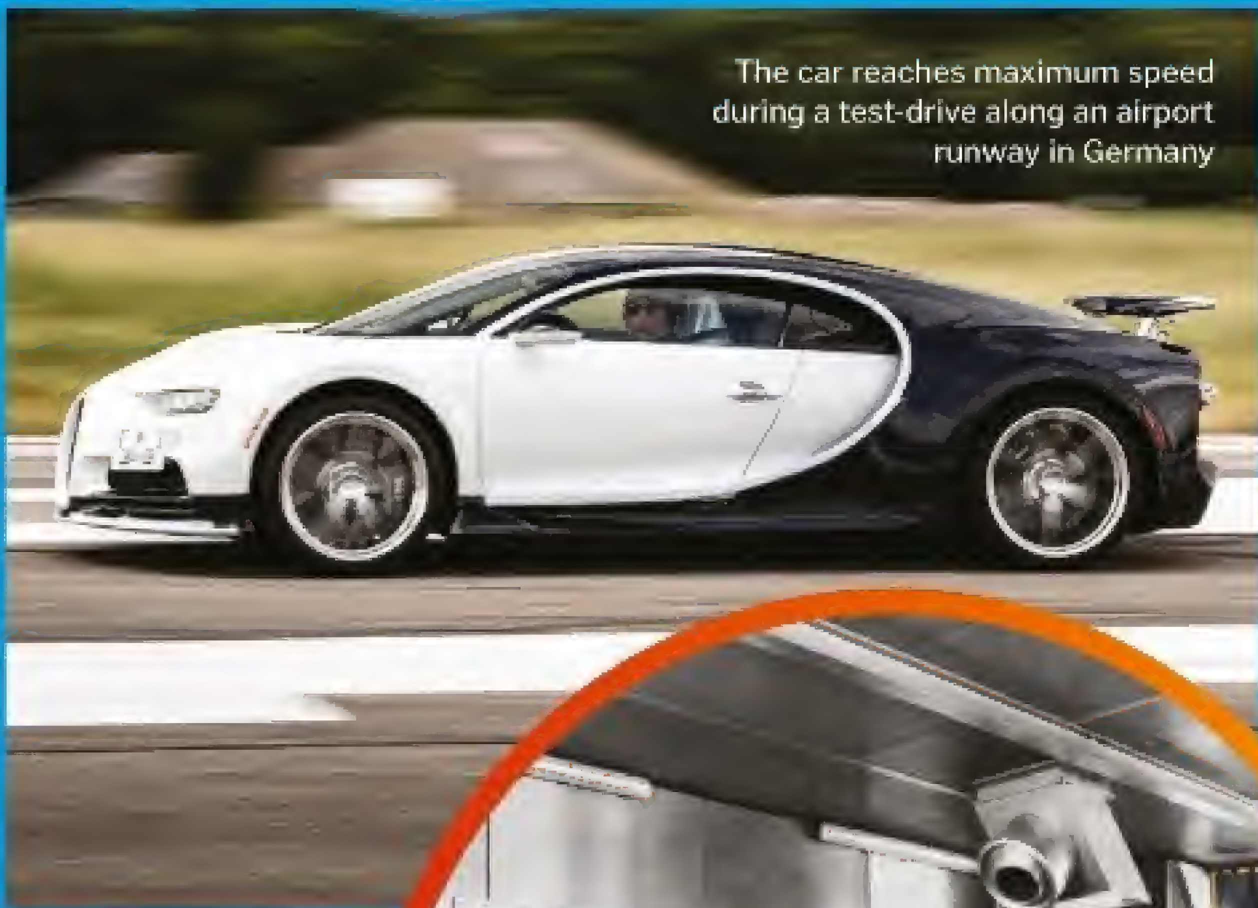
The device that engineers use to see how much power a supercar can produce

Sensors
Sensor readouts can show how hot the engine gets and how much the car's structure distorts at intense speeds.

Data analysis
The dynamometer measures torque, which is how much force the engine must generate to turn the drum at a given speed.

Rolling drum
When the rear wheels rotate they turn a drum, and the rate at which it revolves is recorded by a computer.

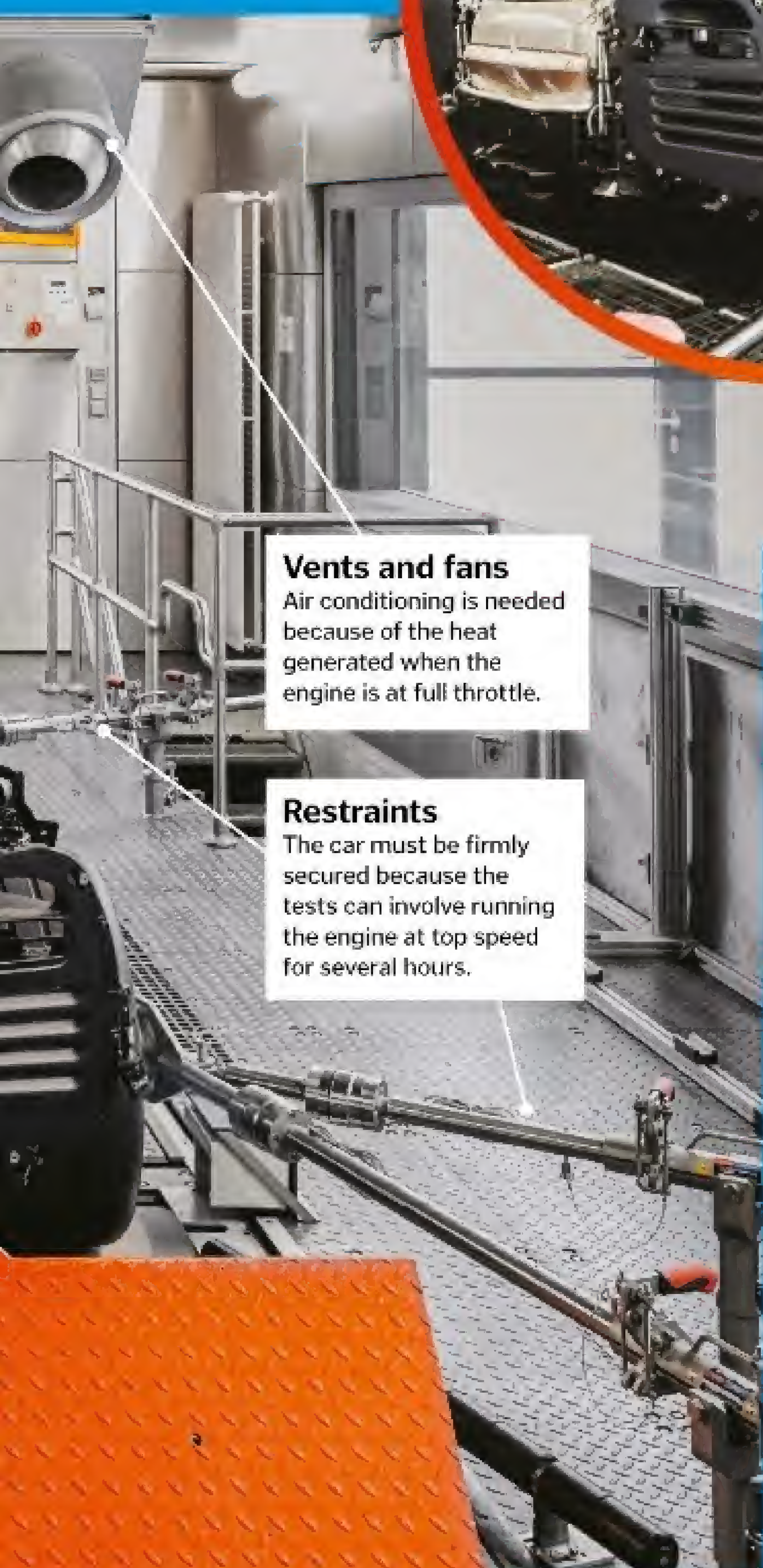
DID YOU KNOW? *Bugatti built a special rig to test the engine's resistance to the highest G-forces it would be exposed to*



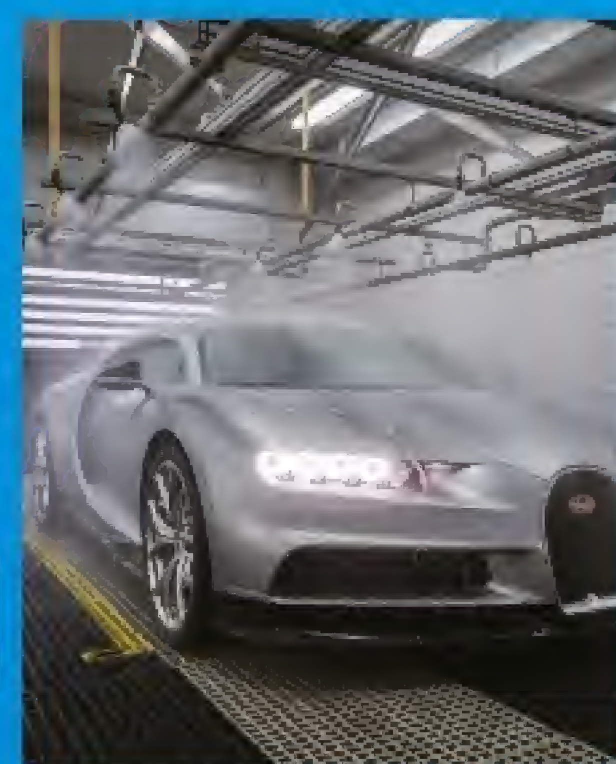
The car reaches maximum speed during a test-drive along an airport runway in Germany

Interior features made of leather or a leather-carbon fibre combination take days to fit

The rolling dynamometer is so powerful that excess electricity is fed to Molsheim's grid



Plastic foil coats the Chiron during its test-drive so the paintwork isn't chipped



The Chiron is drenched by monsoon-strength showers to check for leaks

"Engineers studied a scale model in a wind tunnel to map air flow around the car"

Every feature is extensively tested, including the car's rear-view camera

the oncoming air, which helps to slow the car down safely.

Also acting to bring the car to a stop are massive disc brakes made of carbon, ceramic and titanium. These discs are roasted in an oven at almost 1,000 degrees Celsius to ensure they won't fail in the most stressful conditions they could be exposed to. Here, also, the car's design enlists oncoming airflows to aid in heat regulation; a small duct behind each headlamp pushes air over the brakes to keep their temperature down.

But no matter how good the brakes are, the car isn't going to stop quickly enough if its tyres don't grip the road. That's why Bugatti asked Michelin to design a tyre unlike any the company had ever made before. Turning to aerospace technology for inspiration, Michelin created something that could survive the strain of braking under the enormous weight of an airliner. They also tested its traction on a course where any road condition the Chiron could face was simulated, even monsoon rains.

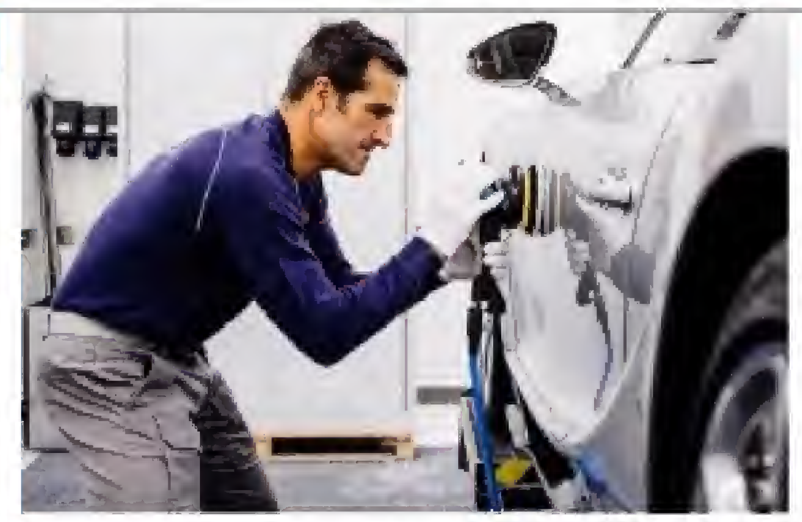
FINAL CHECKS

Back at the Bugatti factory, the Chiron's body also gets a good soaking. Once the paint has dried on the panels, the car is polished thoroughly before being inspected, then polished again. After that, it is moved to a special area where it is subjected to a fake rain storm. If no water is found inside, the luxurious interior is then fitted into the cabin by two people over a period of three days. Control buttons and knobs are made from anodised aluminium and optimally placed within easy reach of the driver. Owners are also offered numerous customisation options that include 23 different colours of leather, 31 colours of stitching and 11 different colours for the seatbelts.

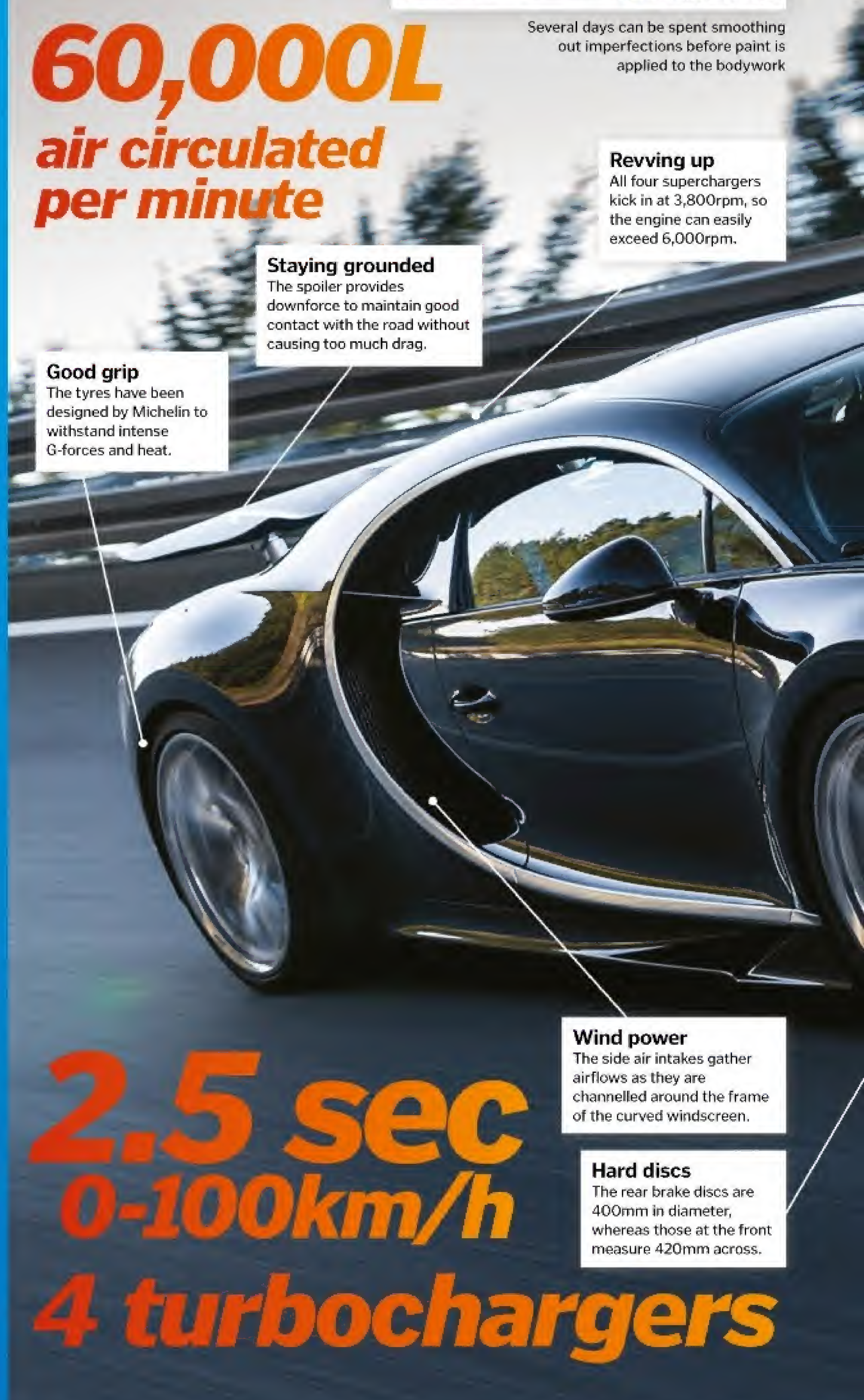
Bugatti is only going to make 500 Chirons. This guarantees that the car has an air of exclusivity. Moreover, it is an inevitable consequence of the six to nine months it takes to build just one car and put it through more than 300 kilometres of road tests. During the final outdoor workouts, the car is wrapped in transparent foil to prevent chips and scratches. With these tests completed, the car is taken to a light-room where it is inspected millimetre by millimetre. Only if it passes these final checks does it get Bugatti's stamp of approval. It's then released to its new owner, who drives away a sumptuous expression of speed and power.

Vital statistics

The big numbers that allow the Bugatti Chiron to leave other cars behind



Several days can be spent smoothing out imperfections before paint is applied to the bodywork



60,000L air circulated per minute

Revving up
All four superchargers kick in at 3,800rpm, so the engine can easily exceed 6,000rpm.

Staying grounded
The spoiler provides downforce to maintain good contact with the road without causing too much drag.

Good grip
The tyres have been designed by Michelin to withstand intense G-forces and heat.

Wind power
The side air intakes gather airflows as they are channelled around the frame of the curved windscreen.

Hard discs
The rear brake discs are 400mm in diameter, whereas those at the front measure 420mm across.

2.5 sec 0-100km/h

4 turbochargers

Another inspection for blemishes is done in the light tunnel

"Bugatti is only going to make 500 Chirons"

Total control
The driver can access all essential functions without having to take either hand off the steering wheel.

Cabin comforts
The interior is luxurious and efficient, with everything in easy reach and made from top grade leather or anodised aluminium.

Bright lights
Bugatti claims that the full-LED projector headlamps are the flattest ever fitted to a car.

Even gaps around the doors are checked to make sure they match Bugatti's strict specifications

16 cylinders

1,500hp

500hp more than the Veyron

Top speed

420km/h (limited)

The Pit-Bull VX

Fast, agile and bulletproof, this armoured response vehicle is one of a new breed of robust police cars that are stopping criminals in their tracks

The Pit-Bull VX is an armoured response vehicle (ARV). Designed specifically for SWAT teams, ARVs offer protection against small arms fire, but without the heavy armour that military vehicles require for protection against cannon fire and anti-tank weapons.

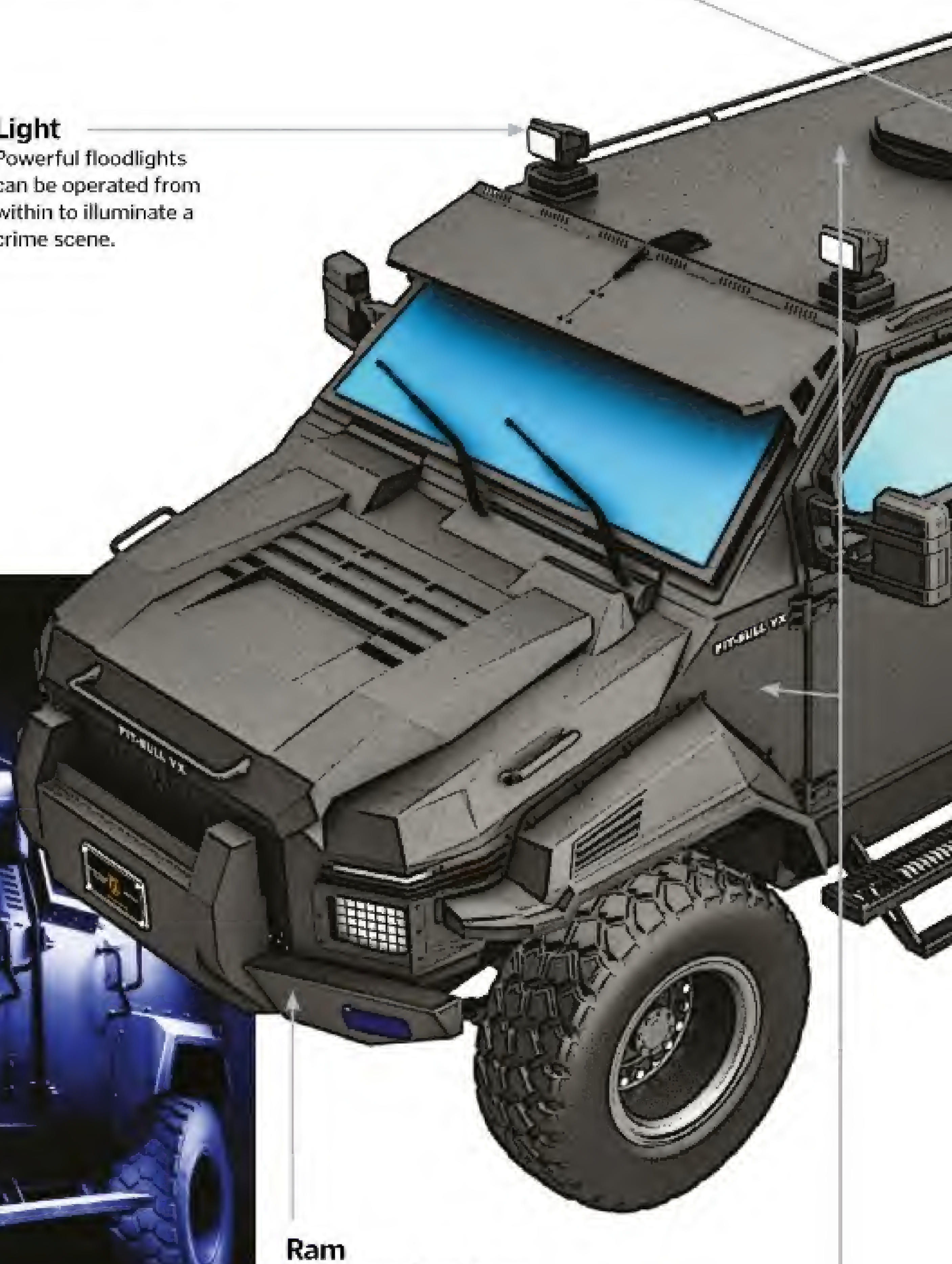
Lighter armour than their military equivalent gives ARVs greater speed and agility. This makes them suitable as first-response vehicles in an emergency situation. Once at a hostile scene an ARV's tough shell means it can be used tactically as a firing post, for dropping an assault team into position or for rescuing hostages.

In the past police teams have tended to use either commercial pick-up trucks or vans. These provide a reasonably fast response time, however offer little more than the means of getting them to a hostile scene. Some SWAT teams have started to drive military vehicles, but due to their weight and lack of mobility they are not designed to be the first responders to an emergency.

ARVs like the Pit-Bull offer a compromise between the speed of an unarmoured vehicle and the protection of an armoured one. As well as offering its eight-officer crew protection against small arms fire, the Pit-Bull is grenade-proof, while firing ports enable the police to use their weapons from within. A PA system and remote-control floodlights mean they can also communicate with the assailants and illuminate an area without having to step out of the vehicle. To cap it all, if negotiations do break down, the 7.5-ton Pit-Bull VX's front bumper has been specially designed to be used as a battering ram.

Inside the mobile fort

Every effort has been taken to make the Pit-Bull VX invincible. Learn how here…



The Pit-Bull VX is designed to cope with high-powered rifles, grenades and even mines

Making an armoured Pit-Bull

The Pit-Bull VX starts life as a Ford F-550. A heavy-duty, four-wheel-drive pick-up truck, it's a workhorse of the US construction industry. The 6.7-litre V6 engine and transmission of the F-550 and chassis remain in the Pit-Bull VX. However, everything else is armoured or purpose built.

The fuel tank, battery and exhaust pipe are fitted with steel armour plating and the suspension is also strengthened. Tubeless run-flat tyres are installed, which function at speeds of up to 48 kilometres (30 miles) per hour when punctured.

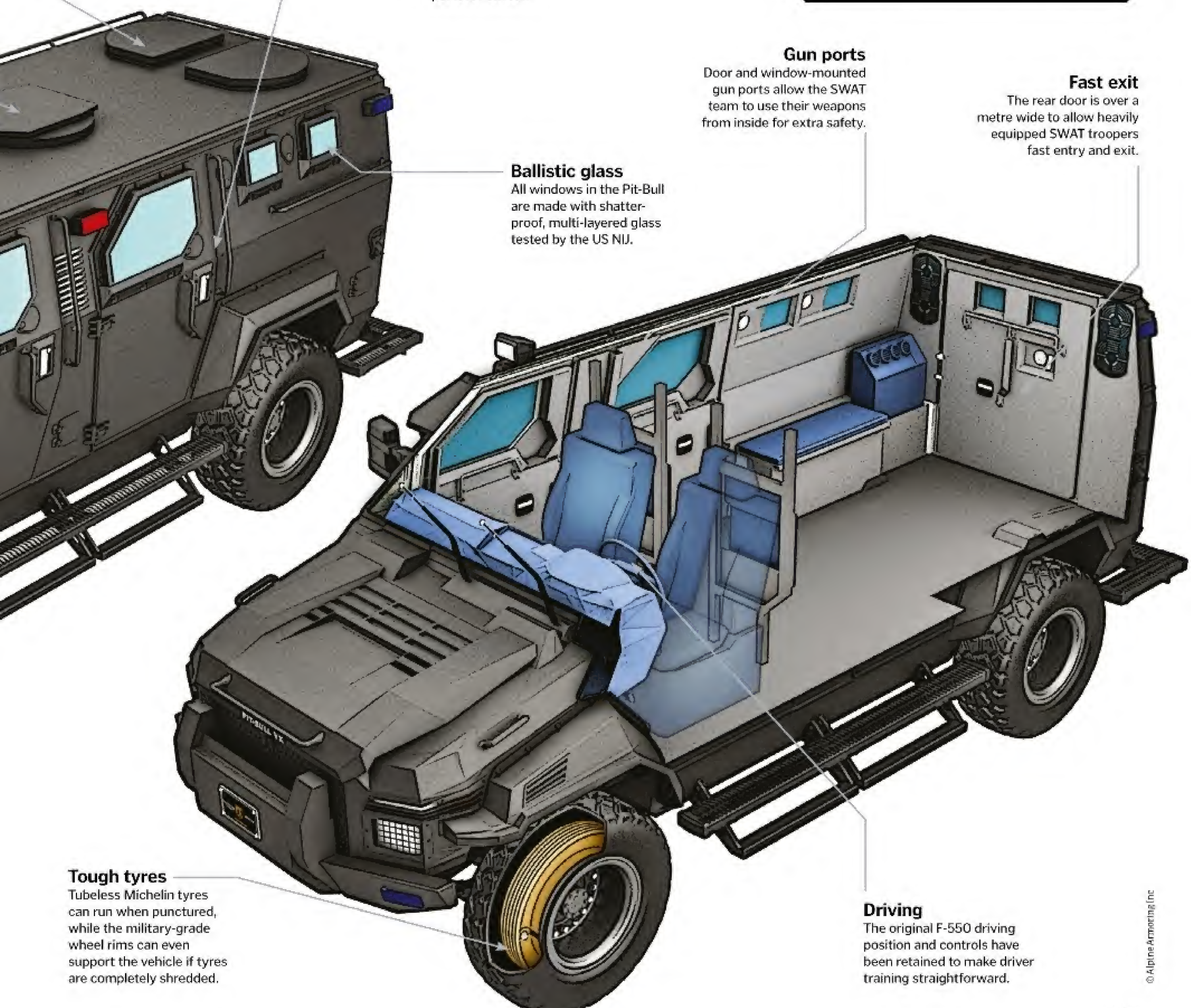
In the event of the tyres being shredded the Pit-Bull VX can still operate on its military-grade wheel rims. Ballistic steel plate is used to provide a mine and grenade-resistant floor, while the main body is made up of overlapping armour plating.

This is built and tested to US National Institute of Justice (NIJ) standards. Despite the armour, the overall weight of the Pit-Bull is 1,000 kilograms (2,200 pounds) less than the F-550 maximum operating limit – plus it still manages to maintain the same speed and performance.

Bulletproof glass

A bulletproof windscreen and windows mean the Pit-Bull VX crew have excellent visibility yet are still protected if they come under fire. Modern bulletproof, or ballistic, glass is constructed in the same way as laminated windscreens. Thin layers of polycarbonate – a transparent plastic – are glued between sheets of glass. The outer layer of glass is often softer so it will flex with the impact of a shot rather than shatter.

A bullet would pierce the outer sheet of glass, but the polycarbonate absorbs the bullet's energy, stopping it from penetrating the inner layer of glass. Depending on the protection levels offered, a bulletproof pane of glass may be comprised of numerous layers of glass and polycarbonate. The Pit-Bull's windows offer protection right up to 7.62 x 51-millimetre (0.3 x 2.0-inch)-calibre ammunition – eg an AK-47.



No gaps
Armour overlaps on all five doors so there's no entry point for bullets.

Gun ports
Door and window-mounted gun ports allow the SWAT team to use their weapons from inside for extra safety.

Fast exit
The rear door is over a metre wide to allow heavily equipped SWAT troopers fast entry and exit.

Ballistic glass
All windows in the Pit-Bull are made with shatter-proof, multi-layered glass tested by the US NIJ.

Tough tyres
Tubeless Michelin tyres can run when punctured, while the military-grade wheel rims can even support the vehicle if tyres are completely shredded.

Driving
The original F-550 driving position and controls have been retained to make driver training straightforward.

MONSTER TRUCKS

Discover the incredible engineering behind this super-sized motorsport

Every year millions of fans around the world travel to watch these magnificent machines race, crash and roar, captivated by their extraordinary power and strength. Once on the sidelines, these mechanised behemoths are now the main attraction.

The sport began with modified pick-up trucks with larger suspension and bigger tyres, but monster trucks have evolved into complete custom builds with giant wheels and impressive ground clearance, as well as custom-built tubular chassis with fibreglass bodies. This can attach to the chassis separately, allowing for easy removal when damaged.

These gravity-defying giants are durable monsters designed to bounce, crash and roll over. Monster trucks captivate audiences by crushing everything in their path. These truck titans typically weigh around 4.5 tons and are capable of making jumps ten metres high and 60 metres long. Few can beat Bigfoot, one of the first ever monster trucks, which managed to leap over a 727 jet plane!

Amateur monster truck driving sounds like a fun hobby, but competition rules mean really ramping up the game. If a driver wants to race, their monster truck must adhere to specific rules. The vehicle must be at least 3.6 metres tall and 3.6 metres wide and fitted with giant 209-kilogram BKT 168-centimetre off-road tyres. These tyres have extra-deep treads to provide optimal traction, which is needed to keep such a colossal truck stable, under control and safe.

Monster trucks usually battle against each other in the form of two versus two racing before a freestyle round, where the mighty machines have the opportunity to show off their spectacular stunts as they take on aerial jumps, wheelies and donuts. It's this freestyle round where drivers demonstrate the power of a monster truck, as caravans, buses and other obstacles are placed in their path to be crushed.

HOW TO BUILD A MONSTER TRUCK

A monster truck starts life as a donor body taken from another vehicle, usually a four-wheel-drive pick-up truck. Most components will be upgraded to be more durable and robust, but it is

"These gravity-defying giants are durable monsters designed to bounce, crash and roll over"

One of the most influential and iconic monster trucks of all time is Grave Digger, with its famous black graveyard paintwork and wild reputation

Despite their size monster trucks are equipped to handle tight turns

The 12-passenger Sin City Hustler is the longest monster truck and was designed as a monster truck limousine for Las Vegas tourists

Monster trucks in the record books

First monster truck back flip

It takes skill and a lot of guts to flip a monster truck backwards in the air. There are claims that people have achieved it outside of competitions, but the Guinness World Record-approved first was successfully performed at Jacksonville Monster Jam by Canadian Cam McQueen in February 2010.

Fastest monster truck

The Raminator doesn't let its giant size and heavy tyres slow it down. Mark Hall broke the record three times in Austin, Texas in the US in December 2014, with each of his runs faster than the one before. On his last attempt he achieved a whopping 159.49 kilometres per hour!

Longest monster truck

Measuring in at an enormous 9.75 metres, Sin City Hustler was built as a monster truck limousine by Brad and Jen Campbell of Big Toyz Racing.

Longest ramp jump

The sky's the limit for the approximately 4,500-kilogram Bad Habit monster truck. In September 2013 in Columbus, Pennsylvania, US, driver Joe Sylvester successfully ramp jumped across 72.42 metres!

Largest monster truck

The largest ever monster truck was built in 1986 and is known as Bigfoot 5. Standing at an incredible 4.7 metres and weighing in at an impressive 17,200 kilograms making it the world's heaviest monster truck. The three-metre-tall tyres were taken from a huge vehicle used in Alaska by the US Army.

helpful if the donor body has an engine and transmission so that some of the parts (including mounting brackets) can be reused.

Parts are upgraded with more heavy-duty replacements in order to transform the truck into a true monster. Often these replacements are taken from ex-military vehicles to ruggedise the steering axles and rear differentials. The suspension is raised an additional 0.9 metres to 2.4 metres to give good ground clearance and to accommodate the giant wheels. An upgraded engine is essential, as well as transmission and transfer-case components suitable for high-impact use. This supplies the horsepower needed to move such a mammoth machine.

SAFETY

Monster trucks crash, they're built to, but this means the safety of the drivers and their fans requires special equipment. Perhaps the most important feature is that monster trucks are equipped with three shut-off switches to quickly turn off the electrics: one within reach of the driver, another in the rear of the truck, and a remote ignition interrupter that allows officials to shut down the engine using a handheld device.

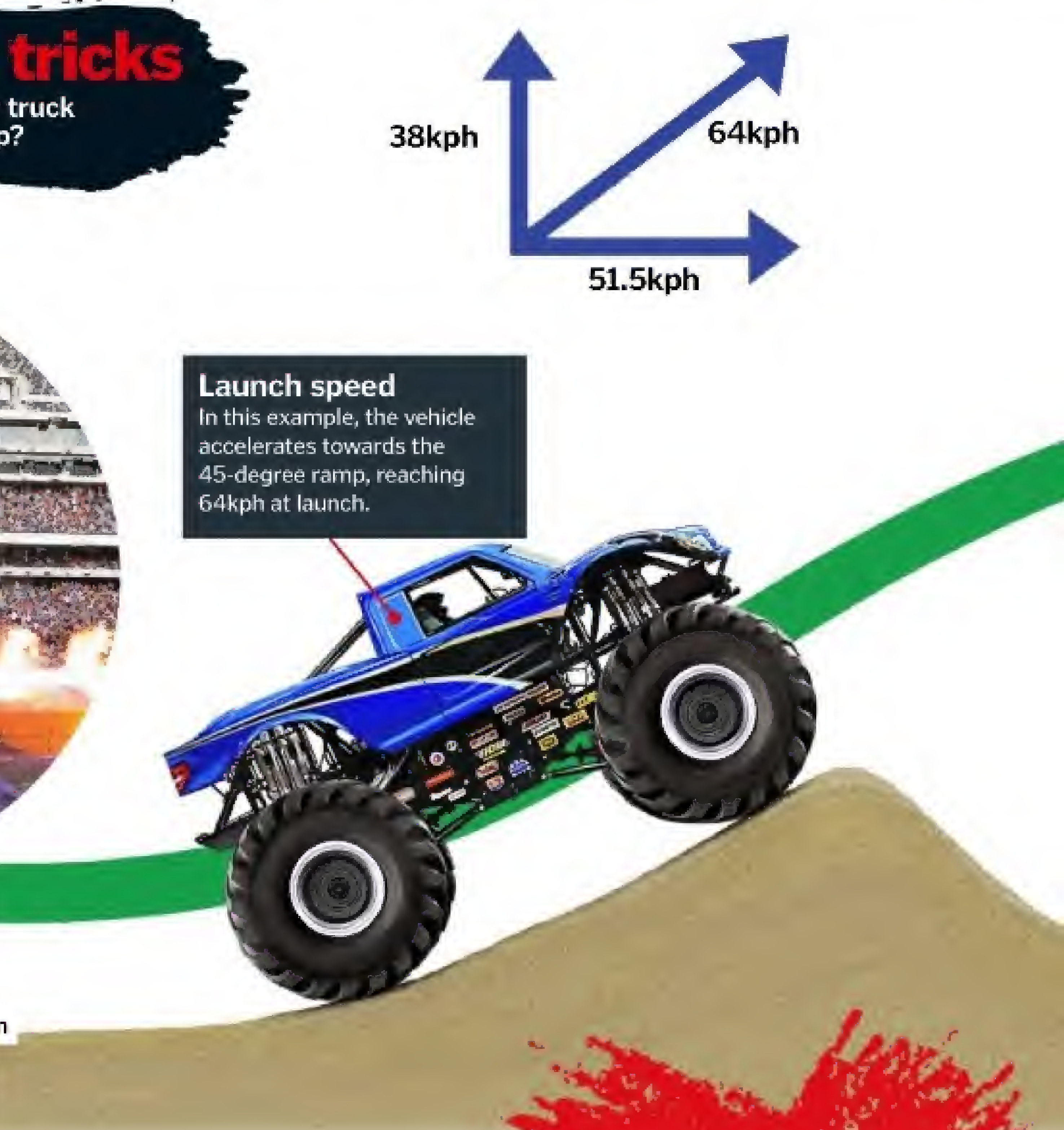
These systems are in place so in the event of a truck rollover the risk of fire is minimised, but they can also be used if the brakes fail or the vehicle appears uncontrollable (and unsafe). Generally, internal moving parts of the truck are shielded to prevent injury, and any high-pressure components are restrained with straps.

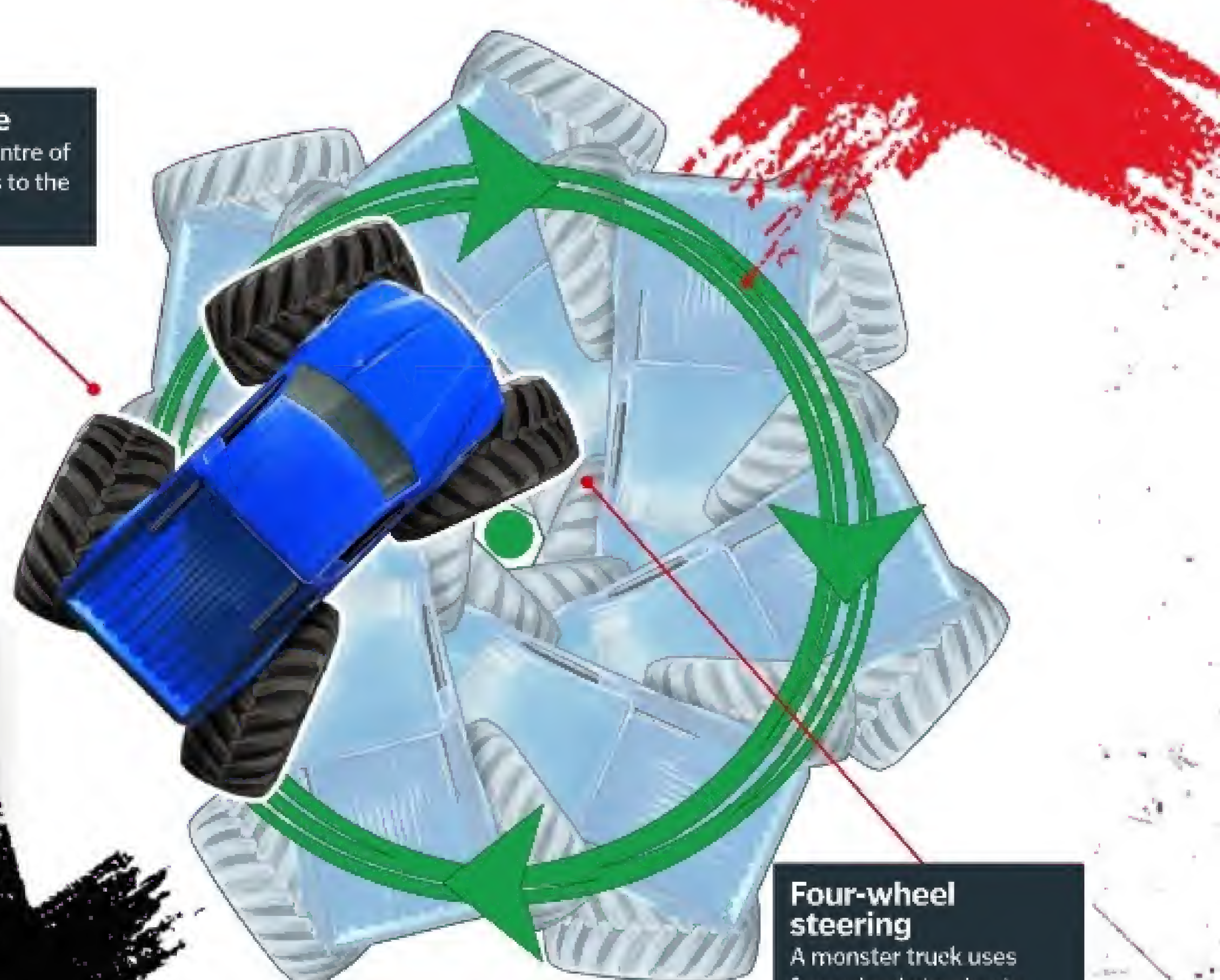
Roll bars and safety cages have to be installed to protect the driver, but drivers are still required to wear specified protective equipment to compete in monster truck competitions, which include a helmet, fireproof suit and a five-point safety harness, as well as head and neck restraints to prevent head injury. Most drivers sit in the centre of the cab, which is shielded with a polycarbonate screen to protect them from stones, mud or debris from the track.

Monster tricks

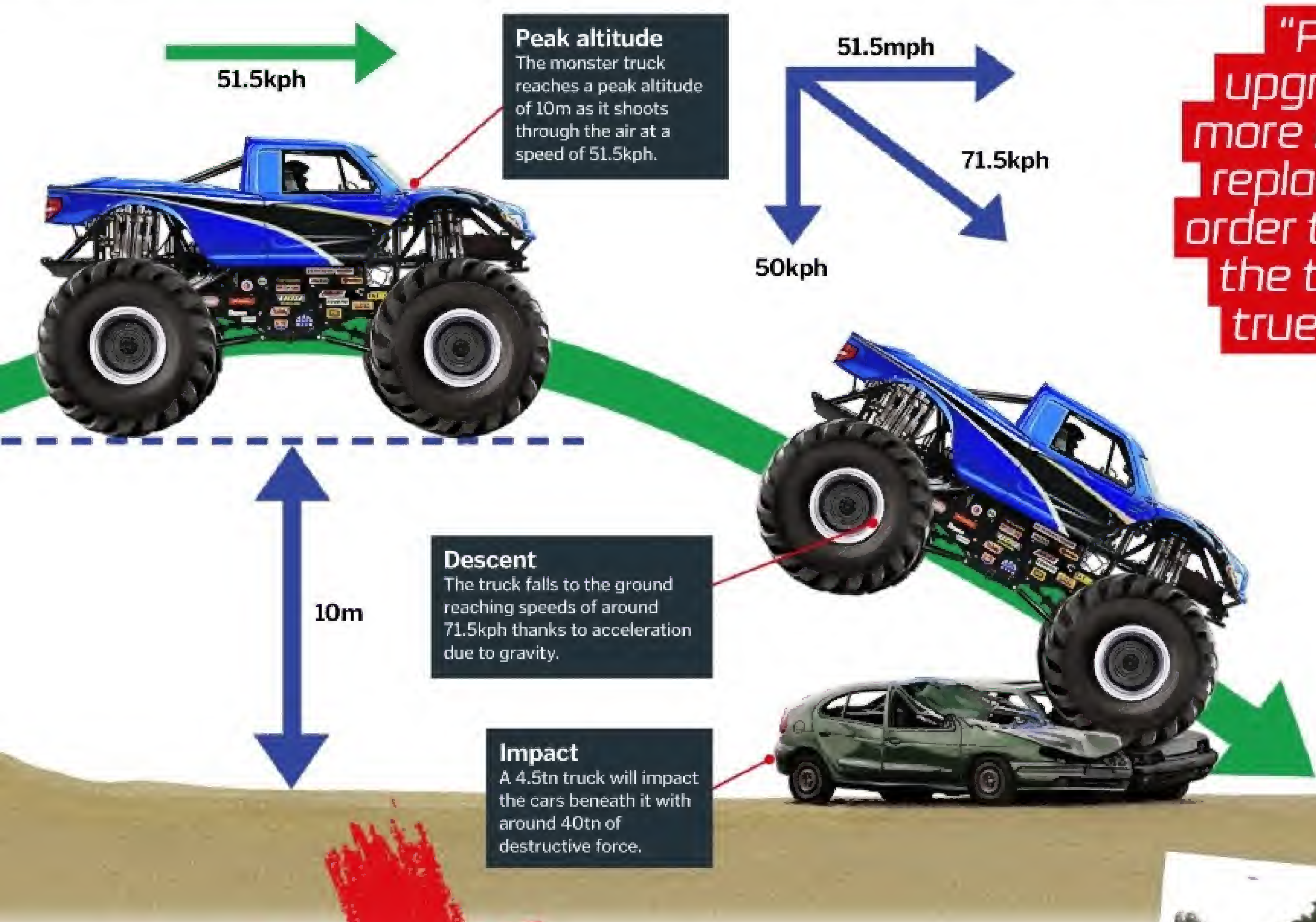
How does a monster truck perform a stunt jump?

World Champion Tom Meents attempts a never-before-done front flip of his Monster Truck, Max-D, at MetLife Stadium on 13 June 2015 in East Rutherford, New Jersey





Monster trucks can land on other cars with such extreme force they can flatten them



"Parts are upgraded with more heavy-duty replacements in order to transform the truck into a true monster"

Monster trucks to the rescue

When 24.5 trillion gallons of rain fell on the US Gulf Coast during Hurricane Harvey in August 2017, tens of thousands of people had to be evacuated from their homes.

Over 200 boats, 300 lorries and 600 people were involved in the efforts to help the flood victims. Joining them were Josh James and his friends from the dirt racetrack Rednecks with Paychecks. These volunteers pulled together and organised their fleet of monster trucks to help in the relief effort. With their trucks standing three metres from the ground, they tackled the fast floodwater and were able to keep their engines free from water where other vehicles would be immobilised.

The makeshift rescue team worked to free emergency vehicles and take them to higher ground, and also helped people stranded on the top floors of their homes get to safety.

Monster truck Old Habits helps residents move a generator in Port Arthur, Texas on 1 September 2017

NEXT-GEN RACE CARS

Revealed: Tech innovations that will change the future of racing

When you think of motorsport, what do you see? Heroic drivers piloting purpose-built high performance machines, or merely loud and dirty cars needlessly polluting the planet? While enthusiasts for the likes of Formula 1, the Indy 500 or Le Mans 24-hour races may opt for the former, it's fair to say there's a perception of the latter among the wider realms of society. However, what you may not know is that, aside from the obvious objective of winning, car manufacturers have always used motorsport as a proving ground for automotive evolution. Engines, suspensions and even the body design of the cars you see on the road today were all originally pioneered on the racetrack, an uncompromising environment where designs and creations are tested to the limit. Without racing we wouldn't have wings or spoilers, turbochargers, or even double-clutch gearboxes. And this evolution isn't always in the name of speed. All of the above has been used to make cars not only faster but cleaner too, increasing efficiency of the engine and therefore reducing fuel consumption, meaning cars can cover a far greater distance before needing to refuel.

And, in our digital age, this gradual evolution has become a sprint to evolve the capabilities of the automobile, beginning of course on the racetrack. In recent years we've witnessed a marked increase in hybrid cars on our roads, which is no coincidence when you consider that the likes of Toyota and Porsche, two of the hybrid market's biggest players, have been racing with hybrids in top-level endurance racing for the last five years.

We can therefore look to current technologies in motorsport to understand what lies ahead in the immediate future of road travel, and that centres around hybrid technology and cars harvesting – rather than merely expending – energy. Vehicles with both internal combustion engines and electric cells are therefore going to be ever more common on the road, with electric energy garnered from recycling old energy when a car is braking.

> "Cars you see on the road today were originally pioneered on the racetrack"

As for the future of racing itself? Well, there's no question it lies with electric power. The World Endurance Championship, responsible for races such as the legendary 24 Hours of Le Mans, are stipulating rules for ever-cleaner cars, while championships such as Formula E are already bringing electric cars to the world stage. If you understand what's happening in racing today, you can see what you're going to be driving on the road in the coming years.


Indy 500 cars are turbocharged to produce up to 700 horsepower


The 24 Hours of Le Mans race has been held almost every year since 1923

F1 has led the way for many years as the most popular form of motor racing

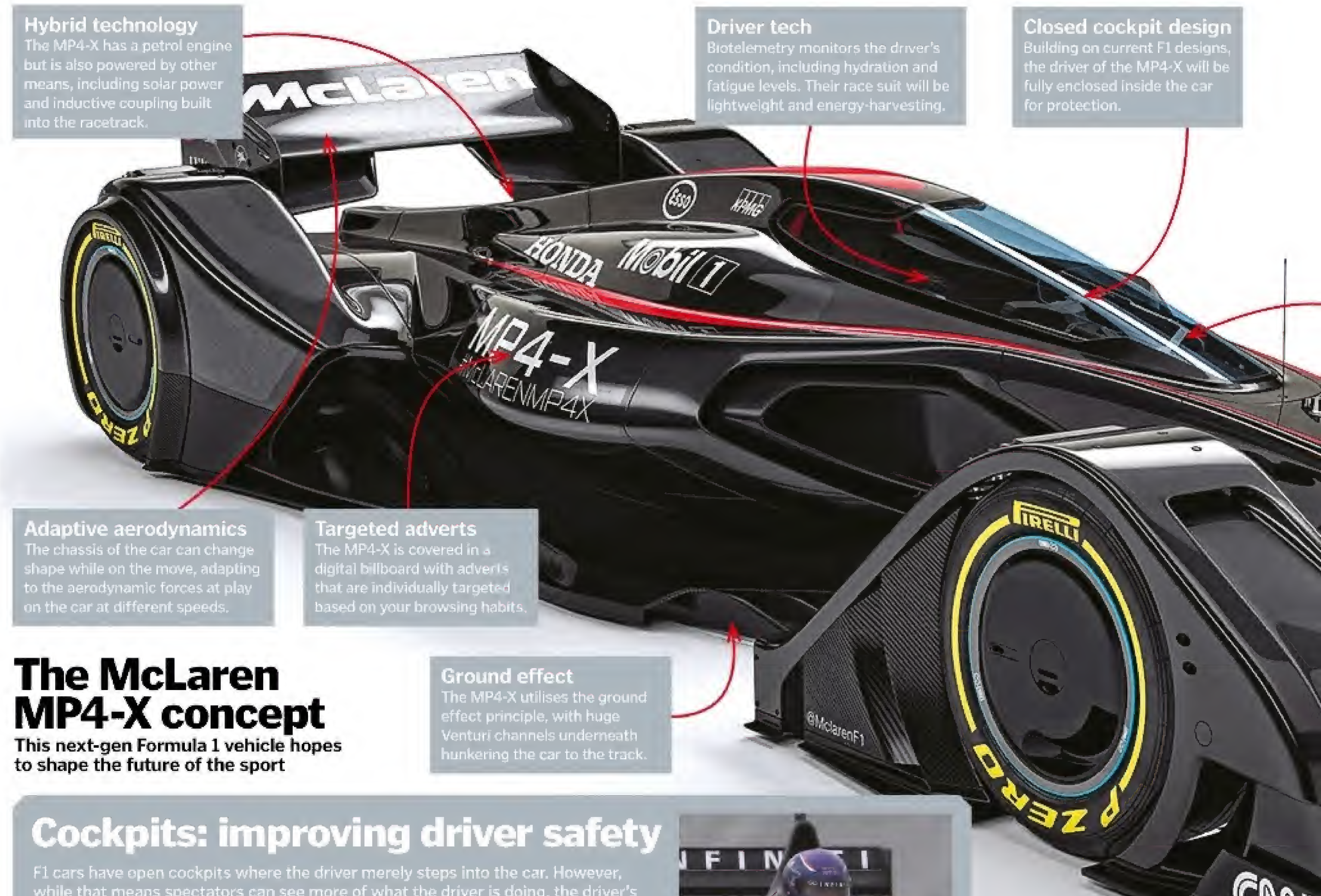
Formula 1 vs Formula E

Which is the future of top-level motor racing?

They may sound like similar motorsport disciplines but Formula 1 (or F1) and Formula E (FE) are different entities altogether. F1 is the long-established championship, offering a global sport that takes the concept of single-seat racing to its most extreme. It has the fastest cars, the history dating back to 1950, and the legends that many generations of motorsporting fans look up to. FE, on the other hand, is something of a new, breakaway phenomenon. Started in 2014, FE uses fully-electric cars with an eye on sustaining energy rather than merely consuming it. Confronting its biggest challenge, FE has sought to make e-racing an attractive proposition for spectators, and so the cars look very similar to their F1 counterparts.

In recent years F1 has started to adopt more green-oriented tech too, with energy recuperation systems effectively dubbing the cars as hybrids. In 2014 the FIA (the governing body for F1) ordered that all cars must cut the amount of fuel they use in a race by a third.

FE is unlikely to be a threat to the commercial success of F1. This is because while F1 visits the world's best circuits, FE makes do with street circuits that don't make for great television, with ugly barriers mapping out courses on bumpy, drain-lined roads rather than sweeping circuits with purpose-built race kerbs. Also, part of the allure of motor racing is the banshee sound of the hard-working engines in race cars, rather than the Scalextric-like whine of electric cars, which gives F1 the upper hand. So it's unlikely that FE will take centre stage anytime soon, and we'll more likely see an adoption of pure electric technologies by F1 teams in the coming years.



The McLaren MP4-X concept

This next-gen Formula 1 vehicle hopes to shape the future of the sport

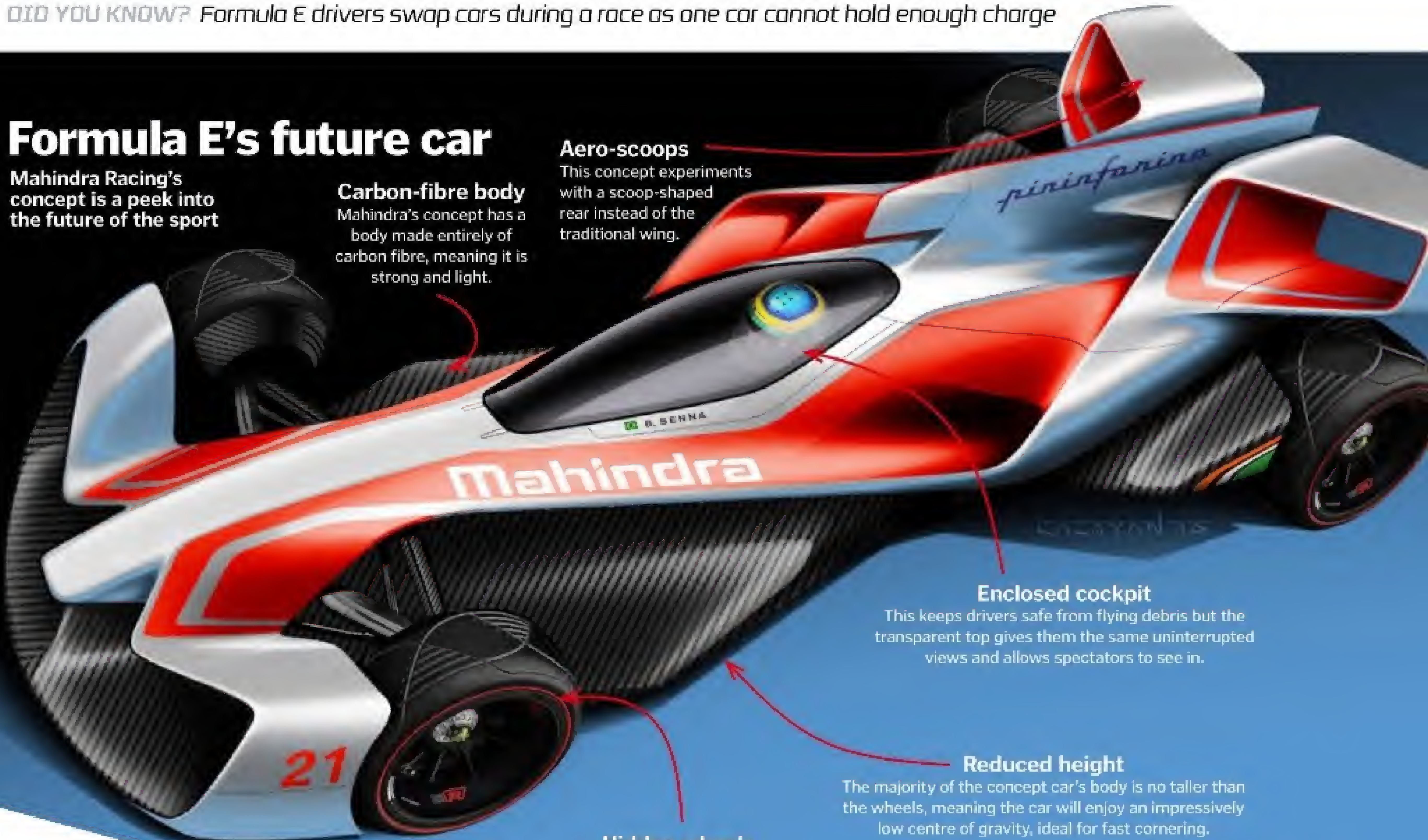
Cockpits: improving driver safety

F1 cars have open cockpits where the driver merely steps into the car. However, while that means spectators can see more of what the driver is doing, the driver's head is exposed. This puts them at substantial risk in the event of a crash or if he or she comes into contact with loose debris or car parts. The tragic accident of Marussia driver Jules Bianchi in 2014 led to teams taking action to dramatically redesign the cockpit with safety in mind. Two designs have emerged: the 'halo' design pioneered by Mercedes and Ferrari, which looks like the straps of a flip flop straddling the driver and protecting them from anything right ahead, or the closed, clear 'aeroscreen' piloted by Red Bull. The FIA has ruled in favour of the halo, which will be used in 2017, although the aeroscreen may also be approved in the future.

Open cockpits, which leave the driver's head exposed, could soon be banished

Formula E's future car

Mahindra Racing's concept is a peek into the future of the sport



Carbon-fibre body
Mahindra's concept has a body made entirely of carbon fibre, meaning it is strong and light.

Aero-scoops
This concept experiments with a scoop-shaped rear instead of the traditional wing.

Enclosed cockpit
This keeps drivers safe from flying debris but the transparent top gives them the same uninterrupted views and allows spectators to see in.

Reduced height
The majority of the concept car's body is no taller than the wheels, meaning the car will enjoy an impressively low centre of gravity, ideal for fast cornering.

Hidden wheels
Wheels enclosed into the body help reduce drag, making the car slip through the air even faster.

360-degree view
Cameras positioned around the McLaren feed live images to the driver's helmet, giving them a 360-view of the car through its walls, much like the tech on a fighter jet.

Reduced drag
Enhancing this ground effect, the wheel guards let air flow over the moving wheels rather than into them, meaning there's also less air resistance on the car.

Noise: pollution or part of the experience?

The subject of noise creates something of a divide in motosport. For racing fans, the powerful roar coming from a car is all part of the experience, but there's a wider responsibility concerning noise pollution to consider (not to mention hearing damage). For the time being, it seems that fan experience is prevailing; after Formula 1 cars switched to turbocharging in 2015, there were mass complaints from spectators as to the flat sound of the new engines. Changes to exhaust pipe regulation for the 2016 season mean some of that signature barrage of sound has been recreated, though many fans remain unconvinced.

Over in Formula E, bosses contemplated running cars with fake engine noises to mask the uninspiring battery whine for spectators. This idea was later ditched, but whether fans will learn to love this eerily quiet motorsport as much as rowdy F1 remains to be seen.

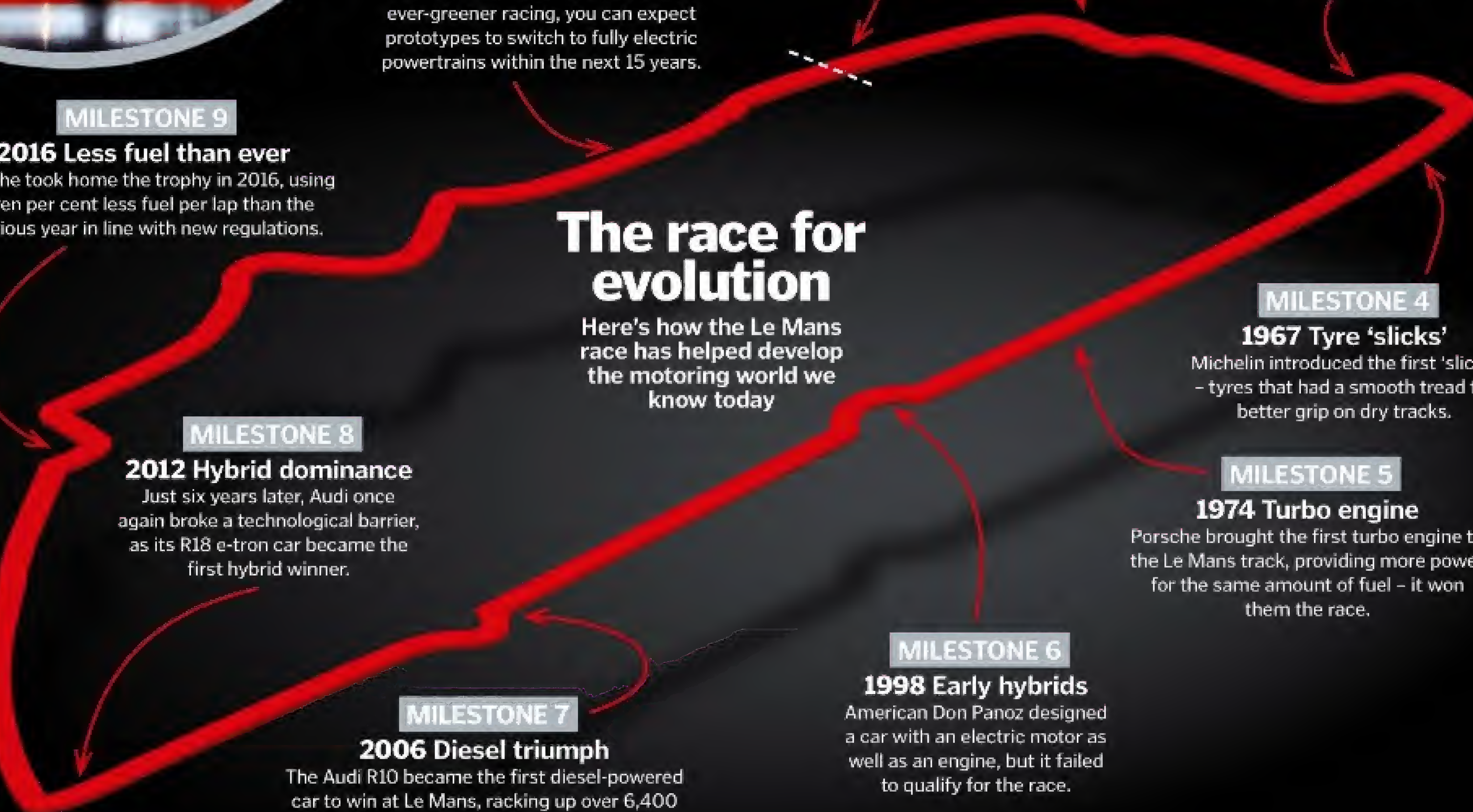
Turbocharged engines have altered the characteristic roar of F1 races

Formula E cars are so quiet that DJ sets often accompany the races

Today's prototypes are advanced racers and their technology will soon be transferred to road cars

The race for evolution

Here's how the Le Mans race has helped develop the motoring world we know today



MILESTONE 1
1923 The first race
The inaugural Le Mans race was won by André Lagache and René Léonard for manufacturer Chenard et Walcker.

MILESTONE 2
1949 Alternative fuels
The Delettrez brothers became the first to compete in the race with a diesel car.

MILESTONE 3
1953 Disc brakes
British manufacturer Jaguar improved braking efficiency by installing disc brakes, and went on to take both first and second place.

MILESTONE 4
1967 Tyre 'slicks'
Michelin introduced the first 'slicks' – tyres that had a smooth tread for better grip on dry tracks.

MILESTONE 5
1974 Turbo engine
Porsche brought the first turbo engine to the Le Mans track, providing more power for the same amount of fuel – it won them the race.

MILESTONE 6
1998 Early hybrids
American Don Panoz designed a car with an electric motor as well as an engine, but it failed to qualify for the race.

MILESTONE 7
2006 Diesel triumph
The Audi R10 became the first diesel-powered car to win at Le Mans, racking up over 6,400 kilometres over the whole weekend.

MILESTONE 8
2012 Hybrid dominance
Just six years later, Audi once again broke a technological barrier, as its R18 e-tron car became the first hybrid winner.

MILESTONE 9
2016 Less fuel than ever
Porsche took home the trophy in 2016, using seven per cent less fuel per lap than the previous year in line with new regulations.

MILESTONE 10
2030 Pure electric racing?
As the hybrid class is pushed for ever-greener racing, you can expect prototypes to switch to fully electric powertrains within the next 15 years.

Le Mans: a test bed for tech

The world's most famous 24-hour race is the proving ground for next-gen car tech

Perhaps more than any other race on Earth, the 24 Hours of Le Mans has always been a proving ground for manufacturers piloting new technologies on cars. Taking the 'win on Sunday, sell on Monday' approach to its utmost level, manufacturers use the famous stage around La Sarthe to twin engineering ingenuity with salesroom success. This perpetual push for evolutionary technology in racing was borne from the race's tradition of allowing prototypes to compete, giving manufacturers a platform to try new technologies from a blank piece of paper rather than trying to shoehorn it into existing road cars. This has proved particularly fruitful in recent years, where Audi prototypes became the first race cars to win at Le Mans first with diesel and later with hybrid power.

From the lessons learned over 24 hours of racing, where cars and their technologies are pushed to their absolute maximum, manufacturers are able to fine tune developments that later appear in showrooms. For example, it is no coincidence that Audi, responsible for thousands of diesel cars on our roads, dominated the last decade at Le Mans with diesel racers, while both Porsche and Toyota, who race hybrids in the prototype LMP1 class, are also two of the biggest manufacturers of hybrid models.

Le Mans isn't just a proving ground for manufacturers. Tyre and fuel companies use the race for real-world research, with Michelin, for example, developing advanced tyre compounds that are long lasting and more environmentally friendly. If successful over the 24-hour period (meanwhile covering a distance of approximately 5,200 kilometres per car) the tyres are likely to be refined further for use on road-going supercars.

Windscreen wipers, as seen on this 1953 racer, were first piloted at Le Mans

Driver's perspective: Nick Tandy

The British pro racing driver for Porsche has enjoyed a long career in GT and top-level motorsport, winning some of the world's most famous races, including the 24 Hours of Le Mans and the 24 Hours of Daytona

How tough is endurance racing on the driver today?
What many people don't realise is you have to be physically fit to drive a top-level motorsport car now. Whether it's Formula 1 or a Le Mans racer, the cars are so fast, have so much grip, and are capable of cornering at very high speeds. That means the forces acting on the car – and you – are extreme (we're talking several G at times), and you have to be fit to not only withstand those forces, especially on your neck, but maintain your concentration throughout to drive the car faster than anyone else. As such we have lots of physical training for endurance racing including core, back, stomach and general heart condition.

How has technology changed motor racing?
It's made cars faster, that's for sure, though in some areas the technology is actually restricted in the name of competition! It's also changed the role of the driver; for example, we no longer change gears using a conventional 'H' pattern manual gear shifter, like you see in some road-going cars today. Instead, we change gears by simply pulling a paddle mounted behind the steering wheel column, which is far easier. The way electronics control the car now might sound boring but you can play around with the parameters more, so it's more exciting. Technology has also made racing safer, don't forget. In the 1960s and 1970s, racing was notorious for incidents and crashes, often fatal. It's a lot different today. Don't get me wrong, drivers still fully understand and accept when they're climbing into a car that motorsport can be dangerous, but there are much better safety systems in place today to prevent injury or worse. The car talks to you now: you can see from various displays exactly how healthy the engine and tyres are, which takes away all our excuses too if we have an 'off' day!

"Technology has made the gap between a good and a great driver much more noticeable"

Nick Tandy is one of Britain's most successful professional racing drivers

Tandy believes technology has given racing drivers more to do, but the sport is now more exciting for spectators

Has this increase in technology made your job easier?
From a driving point of view it's harder as there's more going on, but that's made the gap between a good and a great driver much bigger and more noticeable. It's no longer about merely jumping in a car and driving it fast. It's about learning the car's complex systems to get the best out of it. In the 24 Hours of Le Mans with the prototype cars, you can only use a certain amount of energy per lap on average, so you can't just go completely flat out, you have to find a balance. One aspect that's definitely helped, though, is driving simulators. They're now so good and so realistic that we'll book in hours of time in them prior to races to learn tracks if we've never raced there before. We also use driving simulators to improve our driving style and, in some cases, try out different setups on the car. Without those it would all be down to guesswork once we arrive at a circuit.

What do you think the future of racing is going to be like?
I don't think we'll see fully electric cars in the WEC [World Endurance Championship] but more hybridisation, that's for sure. It'll be faster, more competitive, and more thrilling for fans. Cars are getting more reliable, so we'll see less retirements during the race, and some people are worried that adding more technology will only interfere, but I think the opposite – it's only going to make motorsport, of any discipline, more exciting for everyone.

Indy 500: the world's best race?

This Stateside fixture boasts more than 100 years of evolution

You may think there's not much that can be garnered from cars driving around a four-kilometre long oval, but the famous Indianapolis 500 race – more commonly known as the Indy 500 – has more than a century of racing to its name and has borne witness to some striking innovations in motoring.

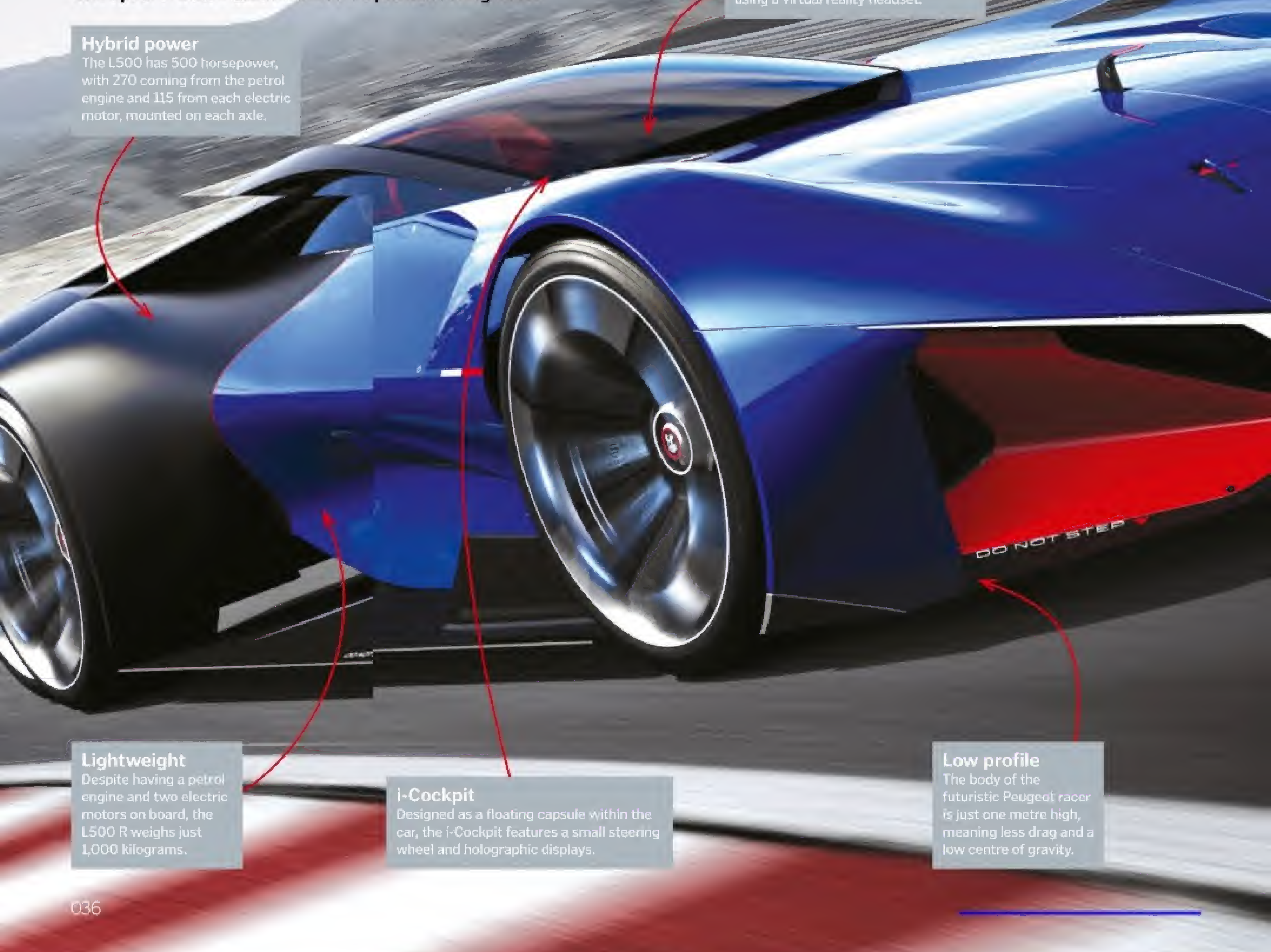
The whole thesis of the Indy 500 circuit was for research. After building the track in 1908, joint owner Carl G Fisher invited manufacturers to test top speeds along the back straight of the venue. By 1911 the famous Indy 500 race was born, in which competitors have to complete 200 laps of the oval track in the fastest time – a distance of 800 kilometres, or 500 miles, the latter giving the race its name. Technological innovations began almost immediately; the race is credited with piloting the first rear-view mirrors in 1911, while the 1920s saw cars – including both privateers and manufacturers such as Fiat, Buick and Mercedes – experiment with supercharging and even four-wheel-drive.

As the years rolled on, the performance of cars improved but also their fuel economy too. The first driver to finish the entire race without a fuel stop was stuntman Cliff Bergere in 1941, despite regulations only permitting smaller engines and fuel tanks than previous years. In 1952, the first race car with a turbocharger was designed, taking inspiration from World War II aircraft, and the 1970s saw inverted wings being added for increased downforce. However, this push for evolution has not come without cost: there have been over 50 motoring-related fatalities at the Indy 500 event to date, which is markedly more than any other race.

Today, though, the Indy 500 competitors look much like those of a Formula 1 event, albeit with bigger engines.

Future of the Indy 500 racer

Peugeot's L500 R Hybrid looks to radically change the concept of the cars used in America's premier racing series



Is Peugeot's L500 R Hybrid the future of racing?

The L500 R Hybrid takes just 19 seconds to cover 1,000m from standstill

From racetrack to road

Ten consumer car technologies that made their name in motorsports

1 Drag Reduction System

F1 cars have adjustable flaps on their rear wings to reduce drag and give a pursuing driver a better chance of overtaking. Many hypercars such as the Porsche 918 and McLaren P1 employ the same tech today.

2 Aerodynamics

Cars are now designed to be more streamlined to cut through the air with less drag, a technique first used on slimline F1 cars.

3 Downforce

Rear wings commonly seen on F1 cars started finding their way onto road cars in the 1970s, improving the grip on the road at high speeds.

4 Hybrid power

Engines can now work in harmony with electric power units, technology originally piloted in endurance racers.

5 Energy recovery

Hybrid and electric vehicles recuperate energy from braking, just like Le Mans racers.

6 Active suspension

Suspensions now have active damping to deal with different terrain and provide a smoother ride.

7 Tyres

Tyres now provide better grip under hot conditions and at great speeds, thanks to developments for racing cars. They're also more streamlined, producing less drag.

8 Push ignition

Many modern cars are replacing the classic key-turning ignition with a push button, inspired by race cars that use them to shave precious seconds off start times.

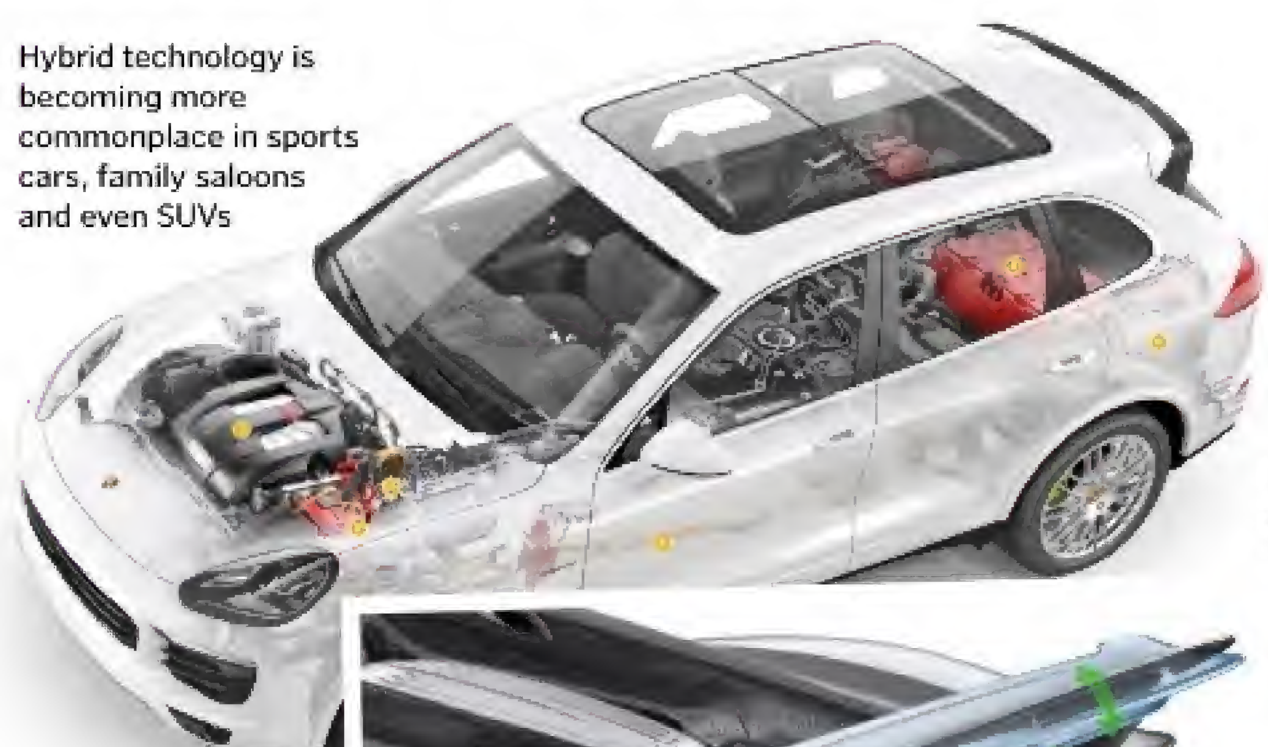
9 Carbon fibre

F1 cars are made almost entirely from carbon fibre. Sports cars now feature carbon-fibre bodywork too, as it is both light and highly durable.

10 Transmission

Semi-automatic gearboxes were first used on race cars in the 1970s and are a common fixture in sports cars today.

Hybrid technology is becoming more commonplace in sports cars, family saloons and even SUVs



Even the humble rear wing, found on high performance sports cars today, was first debuted on the track back in the 1960s

NEXT-GEN MOTORBIKES

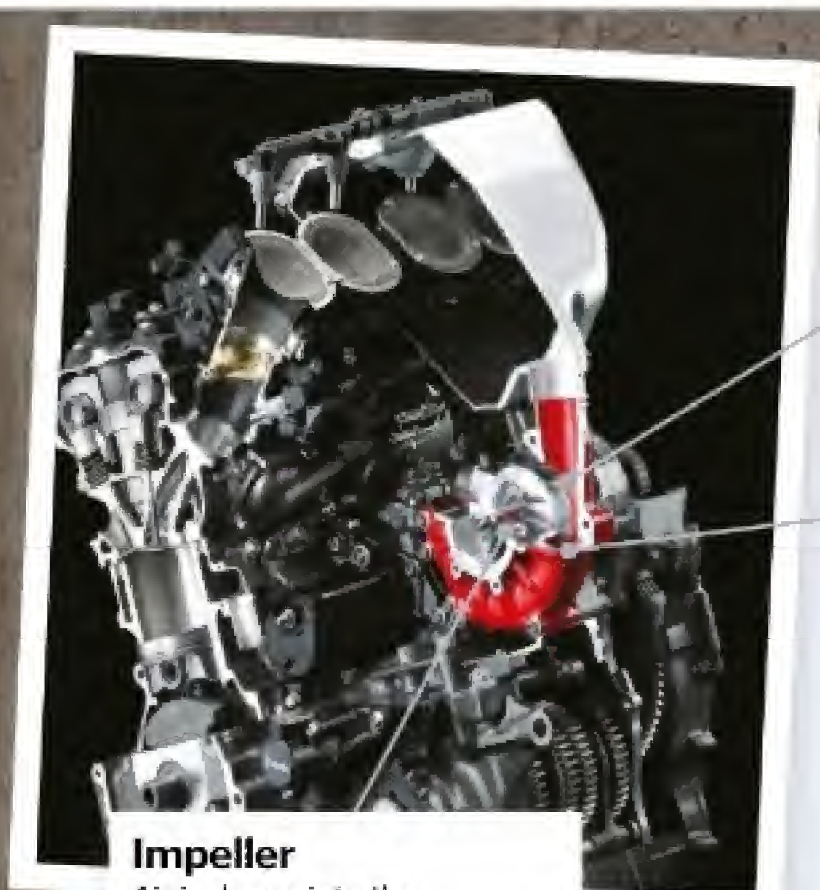
Discover the technology that will make motorcycles the future's most exciting mode of transport

Traditional design principles underlie the Motorrad VISION NEXT 100, BMW's motorbike of the future

If media reports of major technology companies experimenting with self-driving cars have got you thinking that advances in transportation are restricted to vehicles with four wheels, think again. The motorcycle is also heading into a high-tech future every bit as thrilling as that of the car. It makes sense that the same innovations being tested in cars are also on the agenda for motorbike manufacturers. After all, the cool futuristic aesthetics of modern superbikes have given them a prominent place in popular culture, such as the comic book series *Judge Dredd* and the movies *Tron* and *Terminator Salvation*. The image of the modern sport bike is perfectly suited to a notion of a future where our machines are sleek, clean and powerful.

On a more down-to-earth level, motorcycle enthusiasts face many of the same issues that car owners struggle with, such as how to keep down the cost of maintenance and fuel and find safer and more environmentally friendly ways to travel. The impetus for improving motorcycle technologies is driven by both commercial and personal interests.

The first production motorcycle, the Hildebrand & Wolfmüller, was built in 1894. Its engine was rated at almost 1,500cc (cubic centimetres), a measure of the volume of the cylinders. Ostensibly, the bigger the cc, the more power a motorcycle engine can produce. But that's far from the whole story, as evidenced by today's fastest motorbikes. Modern motorbike engines are considered to be big at 1000cc. Yet, the top speed of the latest superbikes doesn't fall far short of 320 kilometres per hour, and the Kawasaki Ninja H2R can reach around 400 kilometres per hour. That's almost ten times as fast as the Hildebrand & Wolfmüller could go. These speeds are the result of advances in



Planetary gears
Kawasaki turned to its aerospace division to design gears able to transfer the supercharger's power.

Centrifugal-type supercharger
This type of supercharger essentially force-feeds air into the engine, boosting internal combustion.

Impeller
Air is drawn into the supercharger by the rotation of this component and then pushed into the engine.

Kawasaki Ninja H2R

If it is power you want from a motorcycle, you'll find plenty of it in this mean machine. Indeed, the Kawasaki Ninja H2R is so powerful, it would be illegal to ride one on the road. The design combines principles of physics with precision engineering. As a bike designed for closed course riding only, it has engine components that are specifically designed to ramp up the horsepower far in excess of what is typical for street-legal production motorcycles. Moreover, it comes with a fairing that looks like the front end of a jet fighter, and for good reason. The pointed nose, cowls and wings are shaped at just the right angles to minimize wind resistance and friction-induced heat build-up. But it's not just the mechanics that are top drawer. State-of-the-art electronics ensure that the ride is smooth, safe and under control, even at 400 kilometres per hour.

Fast and furious

This superbike is the result of clever design and cutting-edge engine technology

Wheels up
Launch Control Mode allows the rider to engage maximum acceleration from a standstill without pulling a wheelie.

Electrical connections
The electronic system includes functions to aid cornering, traction, braking, acceleration, steering and gear shifting.

Hot wheels
The World Superbike Championship-styled wheels are made of lightweight cast aluminium, while the rear tyre measures 200mm for maximum traction.

Tough brakes
To ensure effective breaking at very high speeds, the semi-floating brake discs are extra-large.

998cc engine
The moving parts of the four-cylinder engine are fine-tuned to keep up with the supercharger.

Aerodynamic design
The light-weight fairing was designed by aeronautical engineers to generate downforce, which stabilises the bike at high speeds.

"The Kawasaki Ninja H2R is too powerful to ride on the road"

technology that allow motorbike engines to generate extra power or operate more efficiently.

The Ninja H2R, for example, is fitted with a supercharger that boosts the power output of the engine to levels too high for road use. Along with other superbikes such as BMW's S1000RR and Ducati's 1299 Panigale S, it also includes sophisticated features that control the bike's mechanics on the fly to ensure the best possible ride. These include dynamic traction control, which maintains a consistent grip on the road and thereby provides improved manoeuvrability, braking and acceleration. Essentially, a traction control system constantly monitors whether the wheels are turning at the same speed. If a difference is detected, the power going to the rear wheel can be adjusted to slow it down. One example is Italian firm GripOne's 3D-Intelligence system, which receives data from sensors that measure variables such as tyre load, speed and the bike's lean angle up to 200 times per second.

The next generation of motorbikes could be even more manoeuvrable if flexible smart materials supersede conventional jointed bike frames. This idea is built into BMW's Motorrad VISION NEXT 100 concept bike, the German auto maker's vision of two-wheeled transport in the 2040s. The bike's so-called Flexframe is one piece that turns in its entirety in response to

The Hildebrand & Wolfmüller's four-stroke engine was capable of providing speeds of up to 45km/h

steering. This should reduce mechanical stress and wear on moving parts.

Other features of this bike, according to BMW, are tyres that adapt to the terrain and an engine that changes shape to improve aerodynamics depending on whether the bike is stationary or moving. BMW's prototype is also fitted with a digital companion that makes imperceptible changes to the engine to keep it running in an optimum state for the prevailing conditions.

Although state-of-the-art bikes like the VISION NEXT 100 and Ninja H2R have taken on-board computers to the next level, electronic systems that allow a rider to perform actions like braking and shifting gears with a single button are not new. Many premium motorbikes now include ride-by-wire technology as standard, which replaces the old system of cable connections between the rider's controls and the engine. When the rider opens the throttle, for instance, the action is converted to an electrical signal by a transponder. This signal is then sent to the bike's electronic control unit, which initiates the appropriate follow-up action, such as injecting more fuel.

Wireless technology is also linking riders to their bikes through their clothing. Bluetooth-enabled gloves allow riders to control music and answer phone calls. Meanwhile, smart helmets offer the potential for even more sophisticated interaction. Skully captured the headlines in 2014 with a successful Indiegogo campaign that raised money for the development of a helmet that incorporated a rear-view camera, heads-up display (HUD) and a smartphone link for sourcing turn-by-turn directions and hands-free calls. Unfortunately, it never entered production, but it wasn't the only advanced motorbike helmet in development.

Green machines

It isn't quite the same thing as the steam-powered velocipedes of the 19th century, but using hydrogen and oxygen – the constituents of water – in hydrogen fuel cells to power vehicles could make motorcycles greener.

Fuel cells produce electricity through a chemical reaction that strips electrons from hydrogen atoms. Oxygen may later combine with these electrons and the hydrogen atoms, resulting in the production of water as a waste material. Suzuki demonstrated a motorbike called the Crosscage at the Tokyo Motor Show in 2007 that uses a hydrogen fuel cell to charge a lithium-ion battery. However, as appealing as this sounds for its low environmental impact, the Crosscage remains a prototype.

More promising is the use of electrical batteries that can be charged from the mains or a charging station, like Tesla cars. Manufacturers including Zero, Honda and Harley-Davidson are already testing battery-powered motorbikes.

Advanced motorcycles may one day utilise hydrogen as a fuel

Airbus APWorks Light Rider

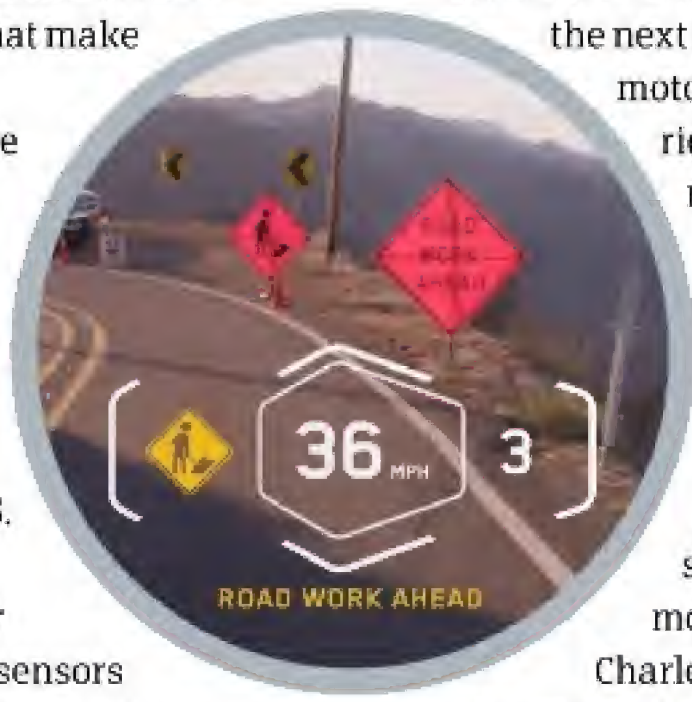
Meet the 3D-printed motorbike that is light enough to lift by hand

The Z-Force electric motor found in Zero motorcycles can be charged at standard electrical outlets

> "Electric bikes could be charged from a charging station, like Tesla cars"

At CES 2016, BMW displayed a design that also incorporates a programmable HUD. Looking to the future, BMW's engineers are even envisaging a world without helmets. As part of the VISION NEXT 100 project, they've designed data glasses that detect where the rider's looking and accordingly display a virtual rear-view mirror, maps or menus that the rider can manipulate with hand gestures.

Tagged with nicknames such as 'widow makers', motorbikes have long had a reputation for being dangerous. Education about speed and wearing good leathers has gone some way towards correcting that, but manufacturers have also been adding tech that make riding safer. A 2015 report published by the Victoria State Government in Australia concluded that anti-lock braking systems (ABS) could reduce the rate of deaths and severe injuries by 31 per cent. Most road bikes now come with at least the option of ABS.



Like bicycles, motorbikes have separate brakes for their front and rear wheels. Speed sensors monitor how fast these wheels are going. When the rider is applying the brakes, the ABS controller uses this data to make minor adjustments to the brakes on one or both wheels, thus ensuring they don't lock and cause the bike to skid or fall over. Even with ABS, many motorcyclists will fall off their bikes at some point. Thankfully, that's less likely to hurt these days due to recent innovations in what riders wear. UK company D3O has developed special polymers that it uses to make flexible but impact-resistant protective body armour for MotoGP and motocross racers. Several companies are also offering jackets that contain airbags. Alpinestars' Tech-Air jackets, for example, include sensors that activate the internal airbags when the jacket is zipped up. If the rider is thrown from the bike, the airbags rapidly inflate to protect their back, kidney areas, chest and shoulders. But even falling off could become a thing of the past with the arrival of self-balancing motorcycles. Honda is calling its version Riding Assist. The concept draws on the company's work in robotics and physics principles associated with the position of the bike's front wheel. Riding Assist would be a boon to novice riders who struggle with balancing, and all riders will have one less thing to worry about when navigating through slow traffic.

With the recent focus on self-driving cars, the next step after self-balancing motorbikes could be bikes that ride themselves. Google has reportedly already begun testing the idea, and a promotional video for Honda's Riding Assist shows the bike following its rider. Then there are the Brigade and Interceptor self-driving police motorbikes. Designed by Charles Bombardier, founder of Imaginactive.org, it's envisaged that these vehicles could scan for traffic violations and other threats to law and order using 3D cameras. While these designs are only speculative, they foretell a future in which motorcycles aren't going to be geared only to enthusiasts. With vehicles filling up our roads, some motorbike manufacturers are investing in ways to reduce our environmental impact. These include using zero emissions power sources, and vehicles like Toyota's i-Road that blur the lines between cars and motorbikes by borrowing design features from both. These innovations are prototypes today but if they prove to be viable, motorbikes could yet become tomorrow's mode of personal transport for the masses.

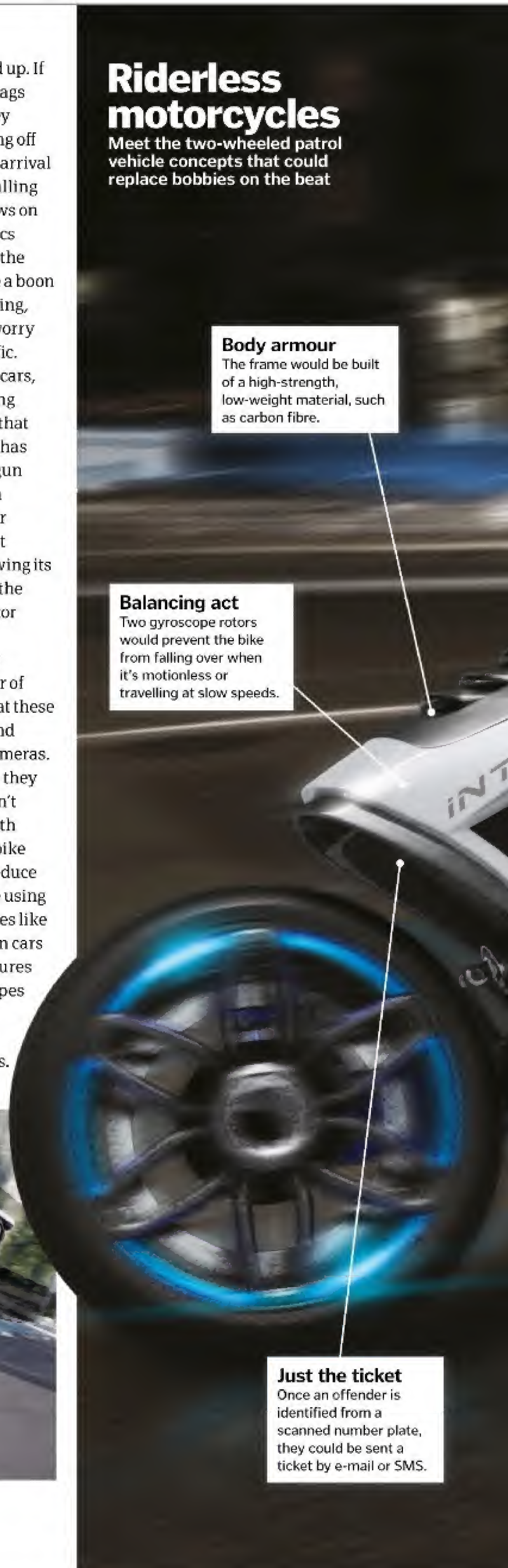
"BMW's engineers are envisaging a world where helmets won't be needed"

ABOVE BMW's concept for a heads-up display shows up-to-date journey information on the helmet's visor

RIGHT Toyota's three-wheeled electric i-Road steers like a car but leans around corners like a motorbike

Riderless motorcycles

Meet the two-wheeled patrol vehicle concepts that could replace bobbies on the beat



Watchful eyes
Two 360-degree panoramic cameras mounted on the top could monitor activity in every direction.

Blues and twos
Flashing strobe lights would signal to attract the attention of an offender such as a speeding driver.

Incident report
If illegal activity is suspected, the cameras could record it and stream the video to police officers stationed nearby.

Electric detective
The 24-horsepower electric engine will be quiet enough to creep up on offenders and be emission-free.

On patrol
These vehicles are designed for slow surveillance of city streets rather than high-speed chases that would drain the battery quickly.

Motorcycle milestones

Major events on the route from steam cycles to superbikes

1867
Ernest Michaux builds the Michaux-Perreaux steam velocipede. Several similar inventions soon appear.

1884
Edward Butler unveils the three-wheeled Butler Petrol Cycle, which has a two-stroke engine.

1894
The Hildebrand & Wolfmüller Motorrad (German for 'motorcycle') enters production.

1906
A new Harley-Davidson motorcycle factory is built in Milwaukee, Wisconsin, US.

1949
The first motorcycle Grand Prix takes place on the Isle of Man.

1951
The Birmingham Small Arms Company becomes the world's largest manufacturer of motorcycles.

1970s
Japanese motorcycle companies, such as Suzuki and Honda, start to dominate.

2010
The specially-designed Ack Attack sets the motorcycle world land-speed record at 606km/h in Utah.

WORLD'S FASTEST TRAINS

DISCOVER THE LEVITATING TRAINS THAT GO FASTER THAN 300MPH

For many of us, the daily train commute is a slow, boring necessity, but what if you could travel at a mind-bending 430 kilometres (267 miles) per hour? That is the reality for passengers travelling on the world's fastest train, the Shanghai Maglev.

High-speed trains have been around since 1964, when a line between Tokyo and Osaka in Japan was built to reach speeds of 210 kilometres (130 miles) per hour. This shortened the time it took to travel between two of Japan's largest cities dramatically, and the world's love of high-speed rail was born.

Many of the world's fastest trains today use magnetic levitation to achieve daily speeds that are over six times the British motorway limit. However, high-speed travel is possible without using magnets. Britain has plans for its second high-speed rail track, from London to Manchester and Leeds via Birmingham, called HS2. The project's technical director, Professor Andrew McNaughton, explains there are other ways to achieve super-speed. "The point of contact between the steel wheel and the steel track is only the size of your fingernail, so we are not too worried about friction, plus the energy required to levitate a train is huge", he says. "HS2 will have 100 horsepower, which is four times more than [in] normal trains. It will only stop at a few stations so won't have to slow down and speed up often at all."

The proposed HS2 train will drastically reduce the time it takes to get between the south and north parts of England by simply using a more powerful engine and fewer stops. However, even though the engine is more powerful, it doesn't actually use that much more energy. The train will use a big burst of power to get up to speed and essentially coast along after that. It will be able to reach a top speed of 360 kilometres (224 miles) per hour and have an average speed of 230 kilometres (143 miles) per hour on its cross-country journey. This will halve the time it takes to get from London to Manchester.

Whether they are suspended in the air or equipped with a monster of an engine to get them off the starting line, high-speed trains are revolutionising the way we travel.

Jet-powered trains

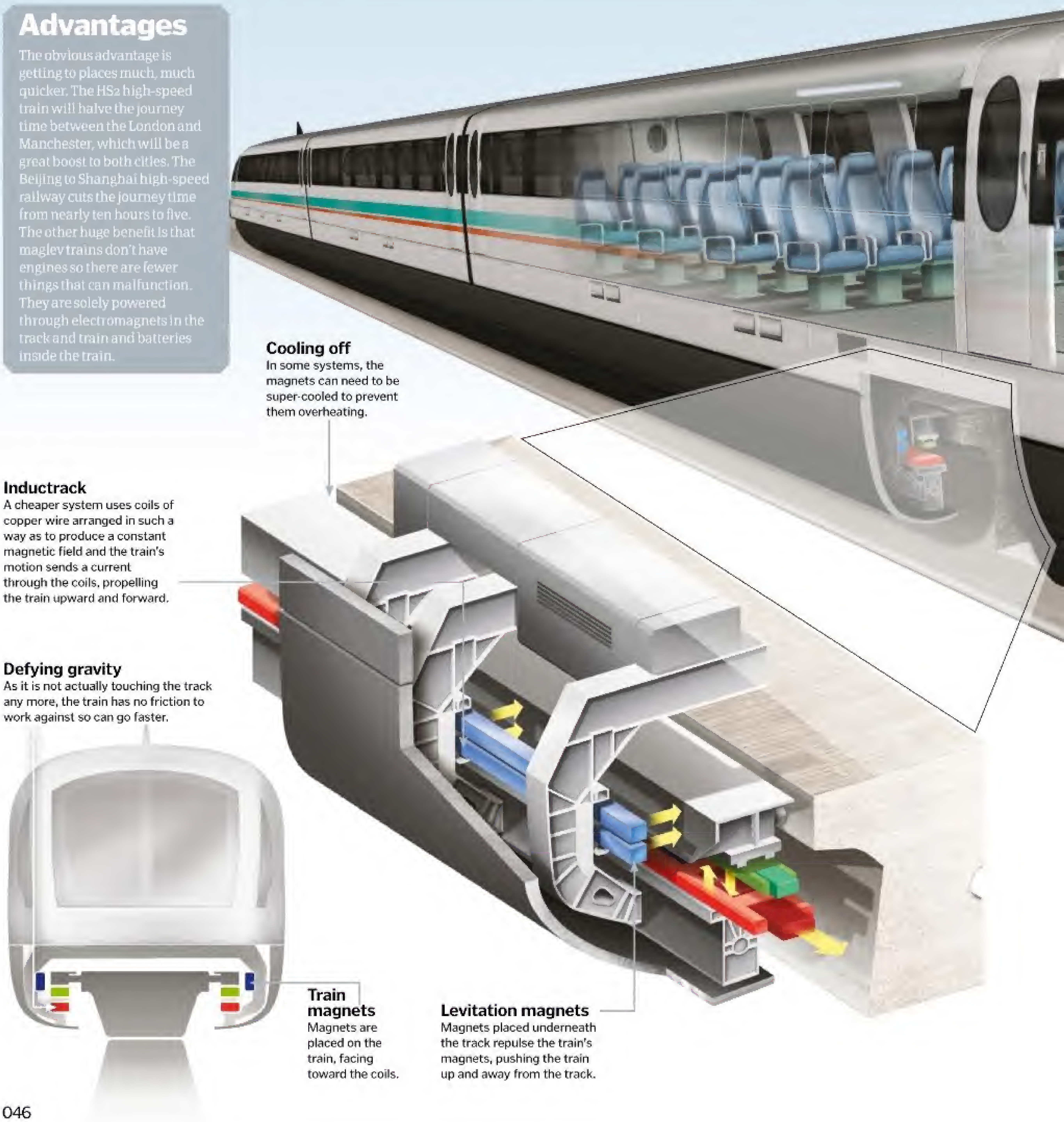
While magnetically driven trains seem to be the future, back in 1966, rockets were all the rage, so naturally someone decided to pop a couple onto a train to see how fast they could go. That person was New York Central Railroad engineer Don Wetzel. He was engaged in an experiment to see how fast he could make a train travel, so used two General Electric J47-19 jet engines on a Budd Rail Diesel Car train with a modified nose for extra streamlining. They named it the Black Beetle and on one run it hit a monumental 295.6 kilometres (183.7 miles) per hour. This remains the record for the fastest train ever to run in the USA, but Wetzel's idea wasn't to last. Rocket-powered trains did not become a viable alternative to steam or electric as they were expensive, difficult to source and provided unmanageable amounts of thrust for commercial use.

Inside a speed machine

How do maglev trains travel hundreds of miles per hour?

Advantages

The obvious advantage is getting to places much, much quicker. The HS2 high-speed train will halve the journey time between the London and Manchester, which will be a great boost to both cities. The Beijing to Shanghai high-speed railway cuts the journey time from nearly ten hours to five. The other huge benefit is that maglev trains don't have engines so there are fewer things that can malfunction. They are solely powered through electromagnets in the track and train and batteries inside the train.



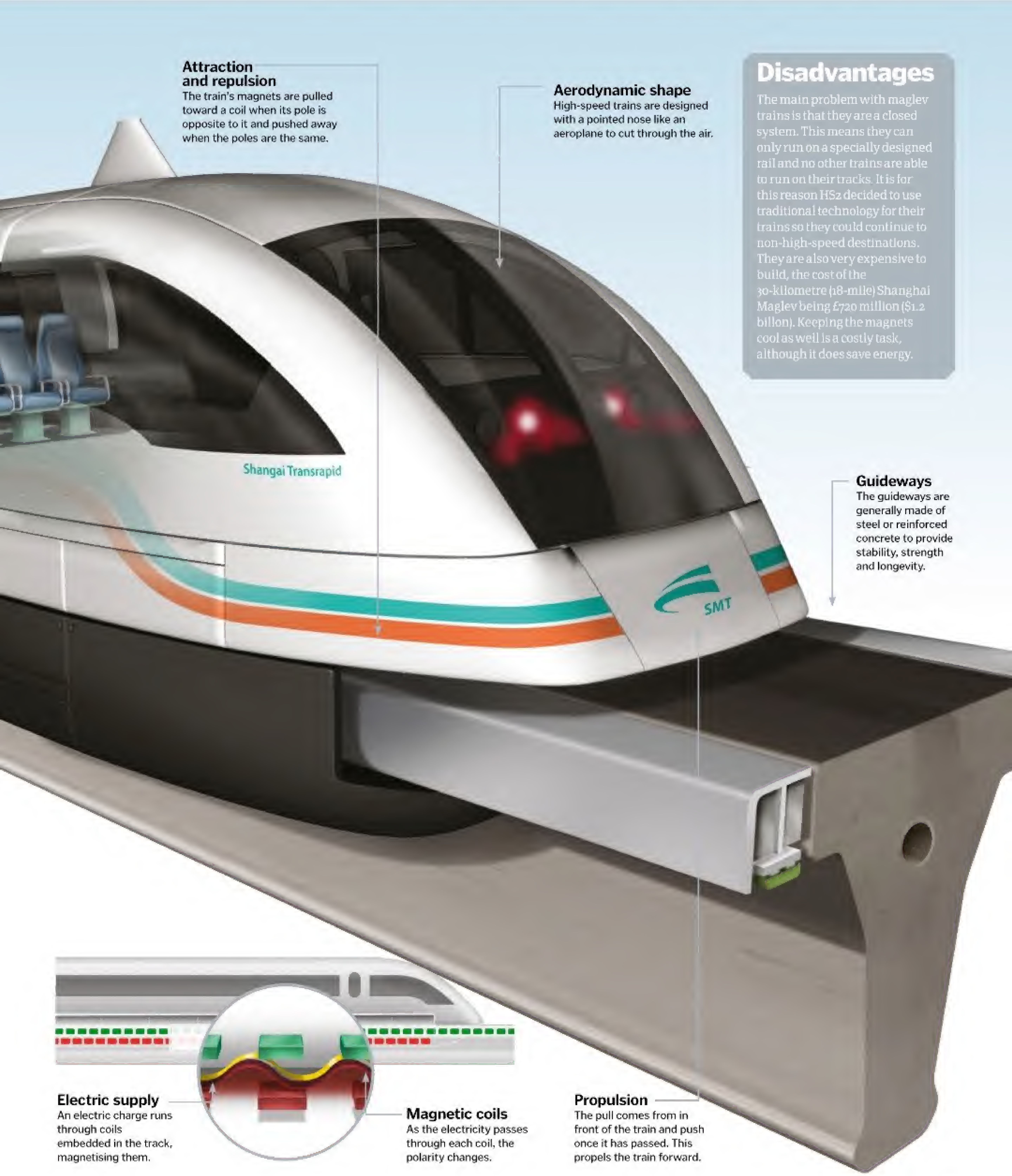
Cooling off
In some systems, the magnets can need to be super-cooled to prevent them overheating.

Inductrack
A cheaper system uses coils of copper wire arranged in such a way as to produce a constant magnetic field and the train's motion sends a current through the coils, propelling the train upward and forward.

Defying gravity
As it is not actually touching the track any more, the train has no friction to work against so can go faster.

Train magnets
Magnets are placed on the train, facing toward the coils.

Levitation magnets
Magnets placed underneath the track repulse the train's magnets, pushing the train up and away from the track.



Attraction and repulsion
The train's magnets are pulled toward a coil when its pole is opposite to it and pushed away when the poles are the same.

Aerodynamic shape
High-speed trains are designed with a pointed nose like an aeroplane to cut through the air.

Disadvantages
The main problem with maglev trains is that they are a closed system. This means they can only run on a specially designed rail and no other trains are able to run on their tracks. It is for this reason HS2 decided to use traditional technology for their trains so they could continue to non-high-speed destinations. They are also very expensive to build, the cost of the 30-kilometre (18-mile) Shanghai Maglev being £720 million ($1.2 billon). Keeping the magnets cool as well is a costly task, although it does save energy.

Guideways
The guideways are generally made of steel or reinforced concrete to provide stability, strength and longevity.

Electric supply
An electric charge runs through coils embedded in the track, magnetising them.

Magnetic coils
As the electricity passes through each coil, the polarity changes.

Propulsion
The pull comes from in front of the train and push once it has passed. This propels the train forward.

The secret behind reaching these incredible speeds is electromagnets. The maximum speed of conventional trains is limited by how powerful the engine is and how fast the wheels turn, but magnetic levitation (maglev) trains have neither of those drawbacks. This is mainly because they don't have engines or wheels! They hover between one and 10 centimetres (0.4 and four inches), suspended by magnets – both on the track and under the train – which repel each other. Magnetic coils ahead of the train are turned on, pulling the train forward with magnetic attraction. As the train reaches the coil, the magnet is turned off and the next one is turned on. The aerodynamic design of the train, together with the absence of friction from wheels and the strong electromagnetic forces, contribute to speeds of up to 430 kilometres (267 miles) per hour.

High-speed trains are constantly being developed and improved. In Germany, engineers have developed an electromagnetic suspension (EMS) system, called Transrapid. This utilises regular electromagnets and an additional set of magnets to guide the train. This prevents the carriages from rocking during turns by wrapping the Transrapid around the guideway, while the maglev sits on a cushion of air. It's reported that these EMS system trains are able to reach blistering speeds of 482 kilometres (300 miles) per hour.

In Japan, a new system currently being developed is called electrodynamic suspension. This involves the electromagnets being super-cooled and conserving energy, making the system much more efficient in terms of energy use, but is very expensive. Another downside to this system is that it needs to run on rubber tyres until it reaches a speed of 100 kilometres (62 miles) per hour, which causes unwanted friction.

The latest development to come out of the world of high-speed train travel is the Inductrack. This uses normal magnets that don't have to be super-cooled or electrically powered, but do involve the train using its own energy source to get up to speed and levitate before the magnets are able to pull it along. These magnets are made from a revolutionary neodymium-iron-boron alloy that dramatically increases the power of the magnetic field.

Who dreamt up magnetic trains?

The idea for magnetic levitation was first proposed in 1914 by Frenchman Emile Bachelet, who developed the rather brilliant idea of a series of magnets being turned on and off along a track to pull a train along. It didn't catch on back then, however, due to the spotty reliability of the electricity supply, but paved the way for the incredible, superfast technology we see today. The improvement in electric technology and the streamlined shapes of trains have allowed them to go faster and faster until they have reached the amazing speeds we see today in the Shanghai Maglev and Japanese Shinkansen.

Shanghai Maglev

The Shanghai Maglev is currently the world's fastest commuter train, reaching a top speed of an eye-watering 430 kilometres (267 miles) per hour, and that's just its operating speed. In testing it hit 500 kilometres (311 miles) per hour. It transports passengers along the Shanghai Maglev Line from Shanghai's Pudong Airport to the Longyang Road train station. The track is 30.5 kilometres (19 miles) long, with a journey time of just seven minutes and 20 seconds, as it travels at an average speed of 251 kilometres (156 miles) per hour. It has been running since 31 December 2002 and available to the public since 2004, so has held the record for the fastest commuter train in the world for an astonishing ten years, a monumental achievement in an industry where innovation and improvement seems to happen with incredible regularity.

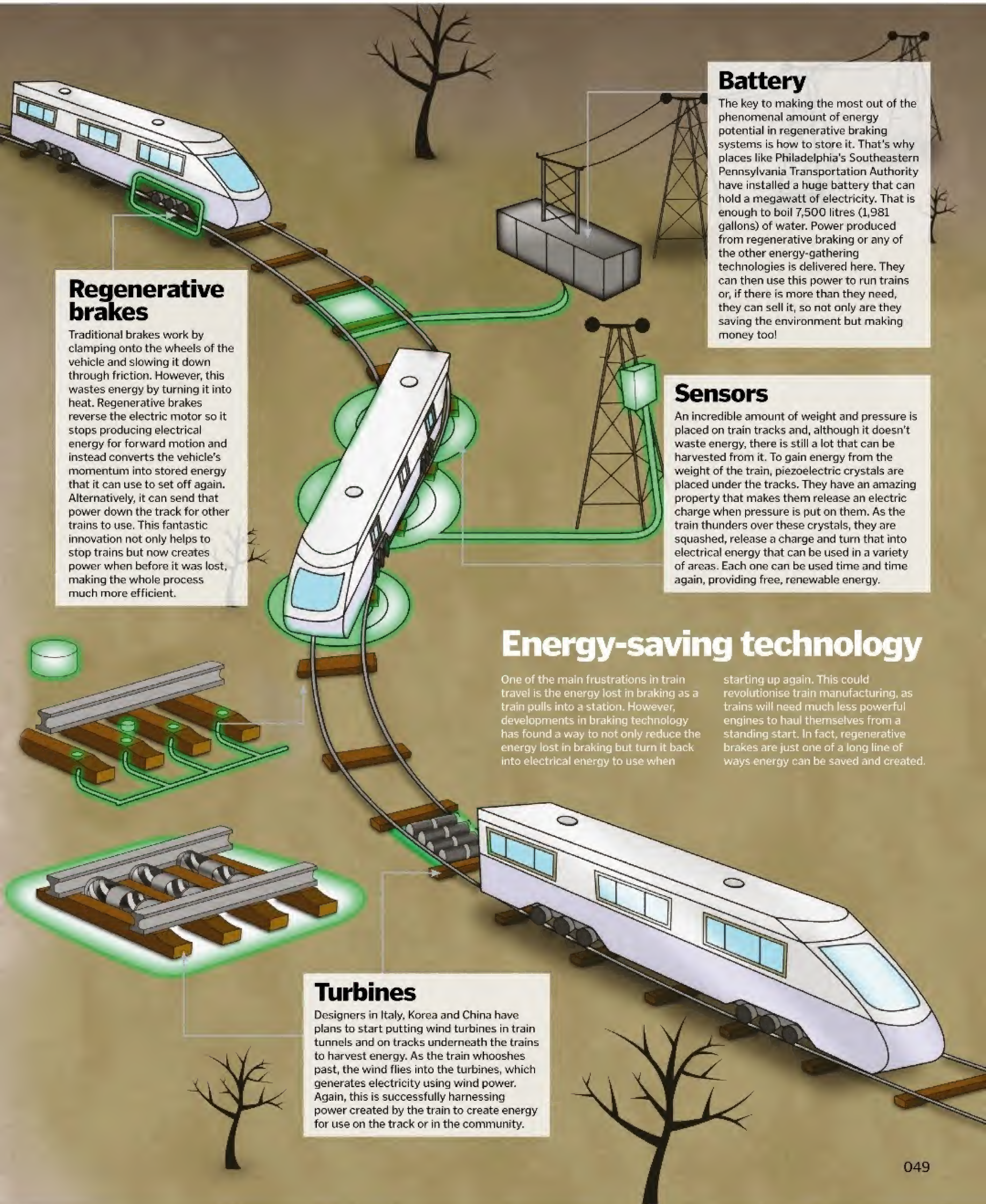
Train stat-ion

430km/h
(267mph)
Shanghai Maglev

(249mph)
2006 BAR Honda F1 car
400km/h

111 HOURS
It would take the AGV Italo 111 hours to circle the equator

7 BILLION
Shinkansen trains have carried over seven billion passengers since 1964, that's the population of the entire planet. To date, there has not been a single accident



Energy-saving technology

One of the main frustrations in train travel is the energy lost in braking as a train pulls into a station. However, developments in braking technology has found a way to not only reduce the energy lost in braking but turn it back into electrical energy to use when starting up again. This could revolutionise train manufacturing, as trains will need much less powerful engines to haul themselves from a standing start. In fact, regenerative brakes are just one of a long line of ways energy can be saved and created.

Regenerative brakes

Traditional brakes work by clamping onto the wheels of the vehicle and slowing it down through friction. However, this wastes energy by turning it into heat. Regenerative brakes reverse the electric motor so it stops producing electrical energy for forward motion and instead converts the vehicle's momentum into stored energy that it can use to set off again. Alternatively, it can send that power down the track for other trains to use. This fantastic innovation not only helps to stop trains but now creates power when before it was lost, making the whole process much more efficient.

Battery

The key to making the most out of the phenomenal amount of energy potential in regenerative braking systems is how to store it. That's why places like Philadelphia's Southeastern Pennsylvania Transportation Authority have installed a huge battery that can hold a megawatt of electricity. That is enough to boil 7,500 litres (1,981 gallons) of water. Power produced from regenerative braking or any of the other energy-gathering technologies is delivered here. They can then use this power to run trains or, if there is more than they need, they can sell it, so not only are they saving the environment but making money too!

Sensors

An incredible amount of weight and pressure is placed on train tracks and, although it doesn't waste energy, there is still a lot that can be harvested from it. To gain energy from the weight of the train, piezoelectric crystals are placed under the tracks. They have an amazing property that makes them release an electric charge when pressure is put on them. As the train thunders over these crystals, they are squashed, release a charge and turn that into electrical energy that can be used in a variety of areas. Each one can be used time and time again, providing free, renewable energy.

Turbines

Designers in Italy, Korea and China have plans to start putting wind turbines in train tunnels and on tracks underneath the trains to harvest energy. As the train whooshes past, the wind flies into the turbines, which generates electricity using wind power. Again, this is successfully harnessing power created by the train to create energy for use on the track or in the community.

Eight incredible railways and trains

Ever since the first working railway was created in England over 400 years ago, in 1603, engines have evolved from primitive coal-powered mechanisms to super-efficient electric motors, meaning that they are able to travel much longer distances, both faster and with less resources for each unit of power. However, this has also meant that humans have had to get constantly more creative with the ways they overcome the challenges of travelling over and under – and sometimes straight through – tricky terrain. Through incredible and imaginative engineering, trains are now able to go over mountains, through hills and even under the sea. There are some lines that represent the dream of a life of luxury, while others are a daunting experience you probably wouldn't want to repeat in a hurry! But which are the most extreme of all?

The world's most dangerous railway

One of the most dangerous railways in history is the Chennai-Rameswaram railway line, which links mainland India with the island of Rameswaram. In 1964 the train, which still has to battle furious crosswinds, was hit by a huge tidal wave, knocking it off the tracks, killing all 115 people on board and demolishing part of the track. Although it has been rebuilt to be safer, it still crawls along the bridge at just over eight kilometres (five miles) per hour.

STAT

The Chennai-Rameswaram train travels at around the same speed as a swimming penguin

The world's longest

If you want to get across the world's largest country, you'll need the world's largest railway. Back in 1891, the Russians built the Trans-Siberian Railway. It spans over 9,200 kilometres (5,700 miles) and transports vital goods like oil, coal and grain. It was finished in 1916 and linked the inhospitable Siberia with the rest of Europe and Asia. Four kilometres (2.5 miles) of track were laid every day using stone to provide a stable surface in the swampy stretches and light metal and wood for the tracks themselves.

STAT

The Trans-Siberian Railway cost around seven times as much as the Golden Gate Bridge.

The world's highest

If you've got a head for heights, it could well be worth taking a trip on the world's highest railway, taking you from China to Tibet. It's called the Qinghai-Tibet railway and treats passengers to incredible views across the Qinghai-Tibetan Plateau. The Lhasa Express reaches a dizzying 5,072 metres (16,640 feet) high with an average elevation of over 4,000 metres (13,123 feet) above sea level. It also houses the world's highest railway station, the Tanggula, which sits at 5,068 metres (16,627 feet) above sea level.

STAT

The highest point of the Qinghai-Tibet railway is 262m (860ft) higher than Mont Blanc.

The world's lowest

The Seikan railway tunnel connects Japan's Honshu and Hokkaido islands and sits 140 metres (460 feet) underneath the seabed, making it lower than any other railway. It was built between 1971 and 1988 and will be able to accommodate the superfast Shinkansen from 2016. The tunnel itself is nearly 54 kilometres (33.6 miles) long, with just under half of it below the seabed. 50 train journeys go through it every day, transporting people and freight between the two islands.

STAT

The tunnel used 85,000 tons of cement, enough to build a 10m (33ft)-wide wall higher than Burj Khalifa.

The world's busiest train station

The Shinjuku Station in Tokyo is the world's busiest station, seeing an astonishing 3.64 million passengers board trains every day. There are 200 exits at the station in order to serve the huge numbers of people that come through its doors daily. A train arrives at one of its platforms every three seconds on average. The most popular line by far is the JR line, which takes nearly half the passengers who use the station.

STAT

More people use the Shinjuku Station every day than live in the country of Latvia

ON THE MAP

The world's longest railways

1 Trans-Siberian Railway
2 Orient Express
3 High-speed Shanghai to Guangzhou
4 Texas Eagle Chicago to LA
5 Toronto to Vancouver
6 Perth to Sydney

The world's longest station platform

In October 2013, work was completed on the longest train platform in the world. It measures a vast 1,366 metres (4,482 feet) and spans the length of the Gorakhpur railway station in India. When they built the station, they made sure they had the world's longest platform, eclipsing the previous record, which also happened to belong to a train station in India, by 294 metres (965 feet).

STAT

It would take Usain Bolt at least two minutes and 11 seconds to run the length of the Gorakhpur platform.

The world's most famous train

If you're asked to name a train, you'll probably either say Thomas the Tank Engine or the Orient Express. As one is fictional, we'll focus on the one that travelled between Paris and Istanbul for 94 years, before being discontinued in 1977. It had four sleeping cars, each of which held ten compartments for snoozing in. It wasn't a technological marvel, but its romantic mystique kept it chugging away for the best part of a century.

STAT

The Orient Express took 60 hours to travel the 3,000km (1,864mi) between Paris and Istanbul.

The world's oldest working train

Built by the UK-based Kitson, Thompson & Hewitson in 1855, the EIR-21 and EIR-22 steam locomotives are still running, transporting passengers between the cities of Alwar and New Delhi in India. Weighing in at a hefty 26 tons, each train can deliver 97 kilowatts (130 horsepower) and can reach 40 kilometres (25 miles) per hour. That's not bad for an almost 160-year duo of steam locomotives…

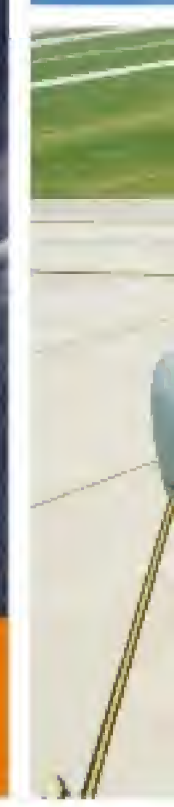
STAT

In the 159 years since EIR-21 and EIR-22 were built, Britain has had six different monarchs.

HOW IT WORKS

AIR

A look inside the giants of the sky



"Discover the tech powering planes of tomorrow"


66


54


72


62


74

SUPER JETS

THE TECH POWERING PLANES OF TOMORROW

■ VERTICAL TAKEOFFS ■ WINDOWLESS DESIGN ■ SELF-HEALING TECHNOLOGY

On 1 January 1914, the world was changed forever when the first commercial flight took to the skies. It flew between the cities of St Petersburg and Tampa in the state of Florida in the United States, lasting a total of 23 minutes and covering a distance of 33.8 kilometres (21 miles).

This landmark event came 11 years after the famous Wright brothers' first powered flight, and marked the first time someone paid to be a passenger on an aircraft. The plane was the boat-like Benoist XIV, which only had room for the pilot and the auction-winning bidder, who coughed up a healthy $400 for the experience. That would be over $9,500 (£5,850) in today's estimated currency value.

Today, people are likely to pay over 100 times that initial amount for a ticket on a suborbital flight. These space planes will take their passengers into orbit, cutting the time from London to the US west coast down to an astonishing 60 minutes. However, it's not just the passengers that are getting a boost. Plans are well under way for smartplanes that can sense when they've got a problem and even heal themselves mid-flight.

The last 100 years have seen startling improvements in commercial aeroplane technology, such as enormous double-decker jets that can carry up to 853 passengers in a single haul, planes that can circle the world in less than two days and, of course, the legendary Concorde that took over 2.5 million people through the sound barrier.

Over the next few pages, we look to the next century of sparkling innovation to see what the aircraft of the future might look like. Commercial flight has come a million miles from that first wooden biplane journey, so buckle up, put your tray into the upright position and please stay seated for the duration of your journey.

SKY WHALE

Is this three-storey concept vehicle the future of travel?

The Airbus A380 currently holds the title for the biggest passenger plane, but that could all change. Called Sky Whale, this concept aeroplane would have a wingspan of 88 metres (289 feet), compared to the A380's 80 metres (262 feet). It would seat 755 passengers, making it economically viable for airlines. The Sky Whale would be able to fly further without refuelling thanks to a double fuselage, and solar cells on the wings would harness power from the Sun. Designed by Oscar Viñals, the aircraft also boasts innovative features such as tilting engines for near-vertical takeoffs. Visit www.behance.net/ovisdesign for more.

Design: Oscar Viñals

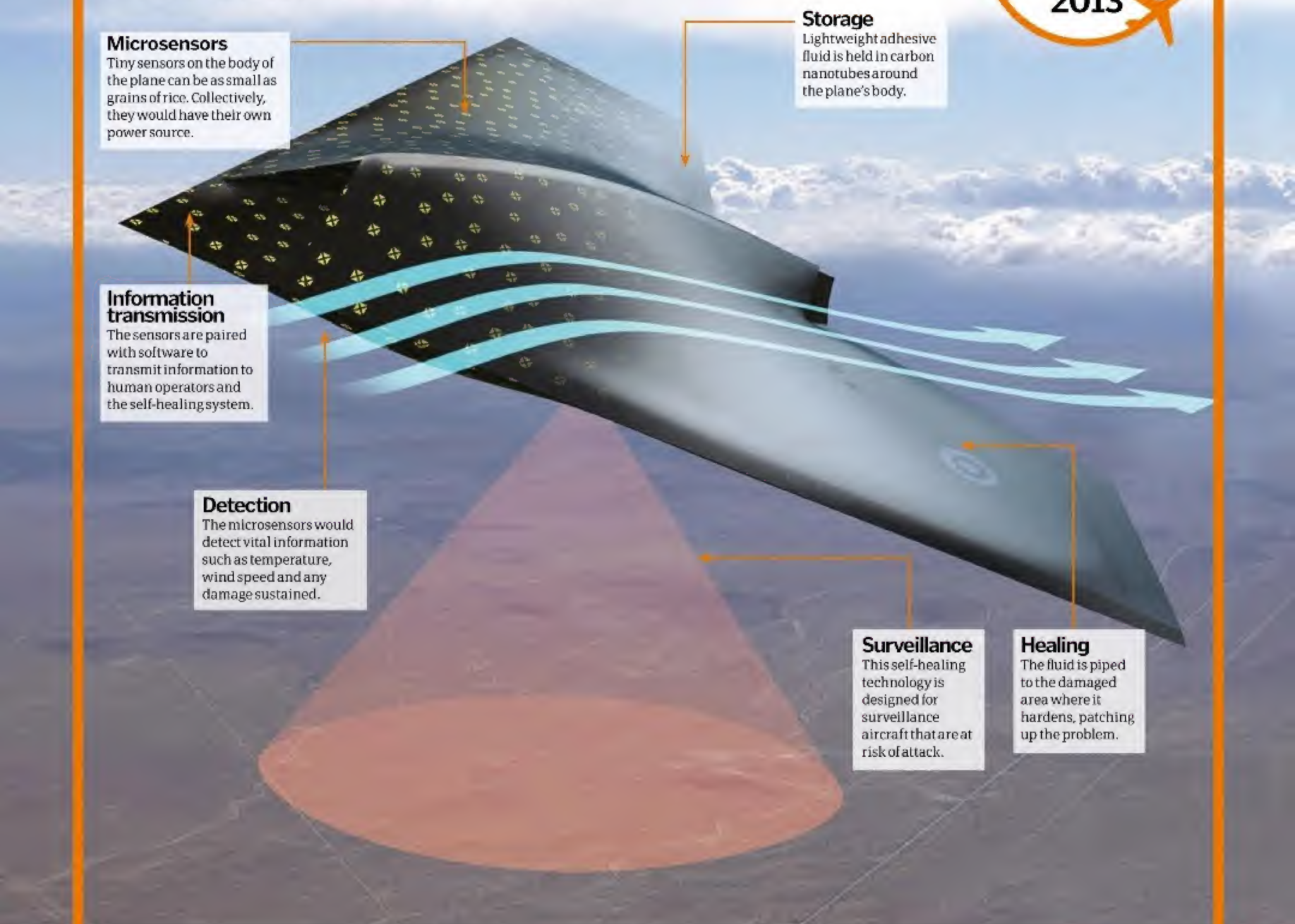

The Sky Whale is a radical reimagining of the commercial aeroplane

THE SURVIVOR

Design: BAE Systems

Self-repairing plane technology with 'human-like' skin

£117m Research costs in 2013



Movies like *The Terminator* may have warned us not to create technology that can heal itself, but the folks at BAE Systems decided to press on regardless. The UK company has unveiled futuristic designs that could revolutionise the method – and speed – that planes are repaired by 2040.

The aircraft's body would be covered in tens of thousands of microsensors that detect wind speed, temperature and any damage sustained. The craft would be able to heal itself in mid-air thanks to a grid of carbon nanotubes that hold a lightweight adhesive fluid. This would be released to the damaged area and quickly harden – like blood forming a scab on a cut – enabling the craft to continue its flight.

This advanced use of materials would create an extremely hardy jet capable of entering the most dangerous of scenarios to complete vital missions, according to a BAE Systems spokesman. They are calling it The Survivor, and that's not the only technology the company believes could be incorporated in military aircraft in the future. Another type of jet, known as The Transformer, would combine smaller sub-aircraft during travel and then split off. This would increase range and save fuel by reducing drag when they fly together.

Despite edging us ever closer to Skynet, this technology is hugely exciting for the aviation industry as smart planes would send maintenance costs and times plummeting, leaving us much more time to plan how to prevent them from rising up against us!

SMARTER SKIES

Design: Airbus

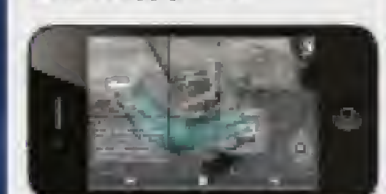
The most energy-efficient plane on the planet

Airbus has always been at the forefront of aviation technology and its futuristic Smarter Skies concept aims to be more efficient and eco-friendly. Here are a few ways in which it's hoping to make future air travel better for passengers and the environment by 2050.

9mn tons of fuel that could be saved

Learn more

To have a good look around the most futuristic cabin ever, download The Future By Airbus app for free from iTunes. It gives you a virtual tour of the flight you could be catching in around 35 years.



ECO-CLIMB

Electromagnetic motors built into the runway would save fuel and reduce noise pollution. They could launch the plane into the air on take-off and capture it as it lands, slowing it down safely. This would save fuel by removing the need for heavy landing gear, but would require every airport to have the same system.

CONCEPT CABIN

Airbus is looking to do away with cramped seats, narrow aisles and class warfare. Instead, planes will be split into zones, such as a relaxation zone, an interaction zone and a smart tech zone. The latter could hold seats made of materials that have a 'memory', morphing to each passenger's body shape.

BETTER TOGETHER

Birds flying in their V formation reduce drag by up to 65 per cent. Airbus is proposing planes on popular routes could club together and fly in formation, reducing fuel burn by ten to 12 per cent. That could save over 10,000 litres (2,640 gallons) of fuel on a journey between London and New York.

IXION **Design:** Technicon

Panoramic views that bring the outside in

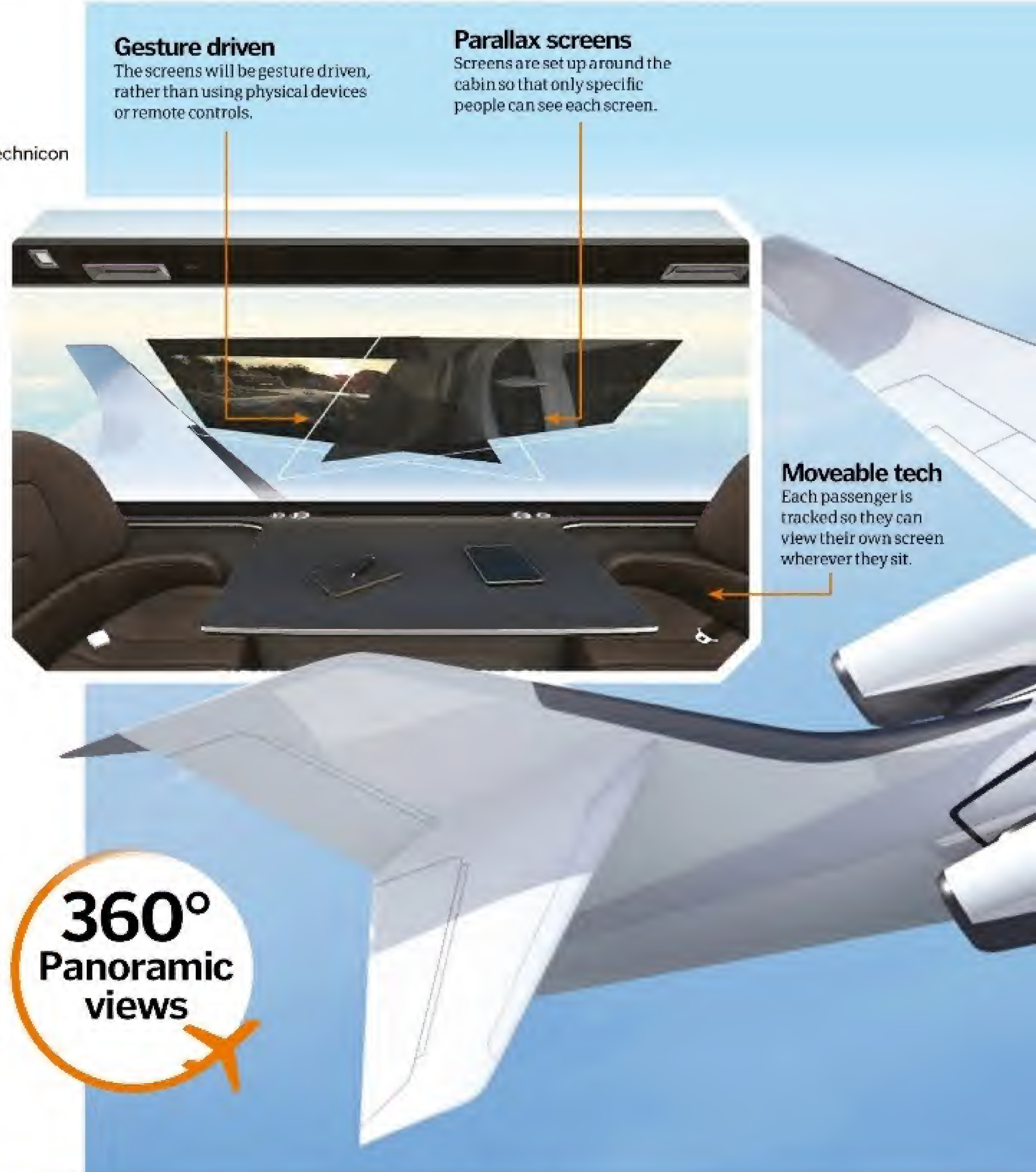
Apart from using newer materials and streamlining, actual aeroplane design has changed very little over the years. However, Technicon Design is an international company trying to change all that with its concept of a windowless jet called the IXION.

Gareth Davies, design director at Technicon Design, explains his vision for future planes: "Windows are complicated things to put into aeroplanes. Each window can add 15 kilograms (33 pounds) to the overall weight and they're not aerodynamic. Our plan is to remove the windows and fit 4K HD cameras to the wings and body that can display images of whatever's outside onto flexible OLED screens inside the plane."

This would give an uninterrupted panoramic view from the inside, while reducing weight and simplifying construction. A myriad of potential cabin moods and themes would be opened up: "You'll be able to control what is displayed on the screens from your smartphone." This could result in a future where passengers travelling over a featureless ocean could be treated to sights like the New York skyline, a desert or even Godzilla taking on downtown Tokyo.

If you don't fancy looking at the same view as everyone else, the concept also suggests parallax screens that can only be seen by the person sitting in a particular seat. To create a truly flexible seating arrangement, passengers would be tracked so their screen follows them to whatever seat they sit in.

Solar panels would also be employed to power internal electronics. This would generate alternative power for the low-voltage systems on board when the engines are idle and save five per cent of the total fuel used. The designs challenge conventional thinking on every level. "We wanted to imagine a possible next step forward", he continues. "The first stage in any innovation is imagination."



Windowless design

The idea behind the windowless design has two main advantages. First, it makes the plane easier to build and more streamlined. Second, and more exciting, is it lets you do crazy and cool things like the image shown here on the right.

4K HD cameras mounted on the wings and body of the plane will be connected to OLED panels in the wall, which will display the outside images in real-time. This is done in the same way as a video camera can display images on a TV using an HDMI cable. The video is taken, sent down a cable to the screens where they are enlarged and reappear as a high-definition live feed.

The screens can also be operated by the passengers, where gesture controls will allow you to make presentations to a group, hold video conferences or watch a film on the wall of the plane. Welcome to the future!

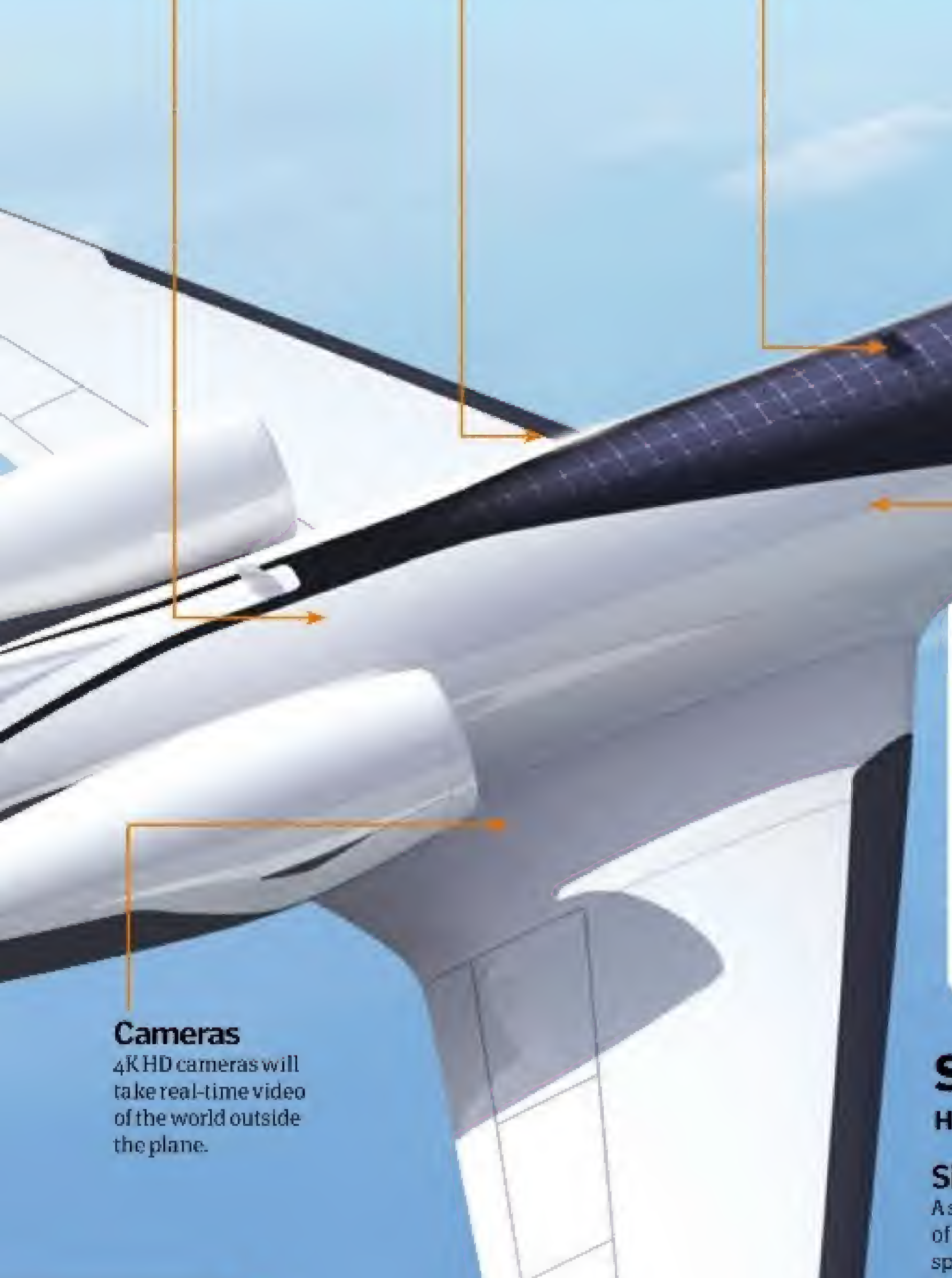
Smartphone enabled
Images from a smartphone can also be displayed on the screens.

Bringing the outside inside
The images from the external cameras will be displayed on OLED screens inside the plane.

Solar panels
Internal electronics will be powered by solar panels on the plane's body.

OLED screens
Thin, flexible plastic screens replace the traditional porthole windows, giving passengers panoramic views.

Windowless body
The lack of windows makes the IXION easier to build, lighter and more streamlined.



Cameras
4K HD cameras will take real-time video of the world outside the plane.

Passengers could be treated to a panoramic view of the world outside their plane. Would you dare look down?

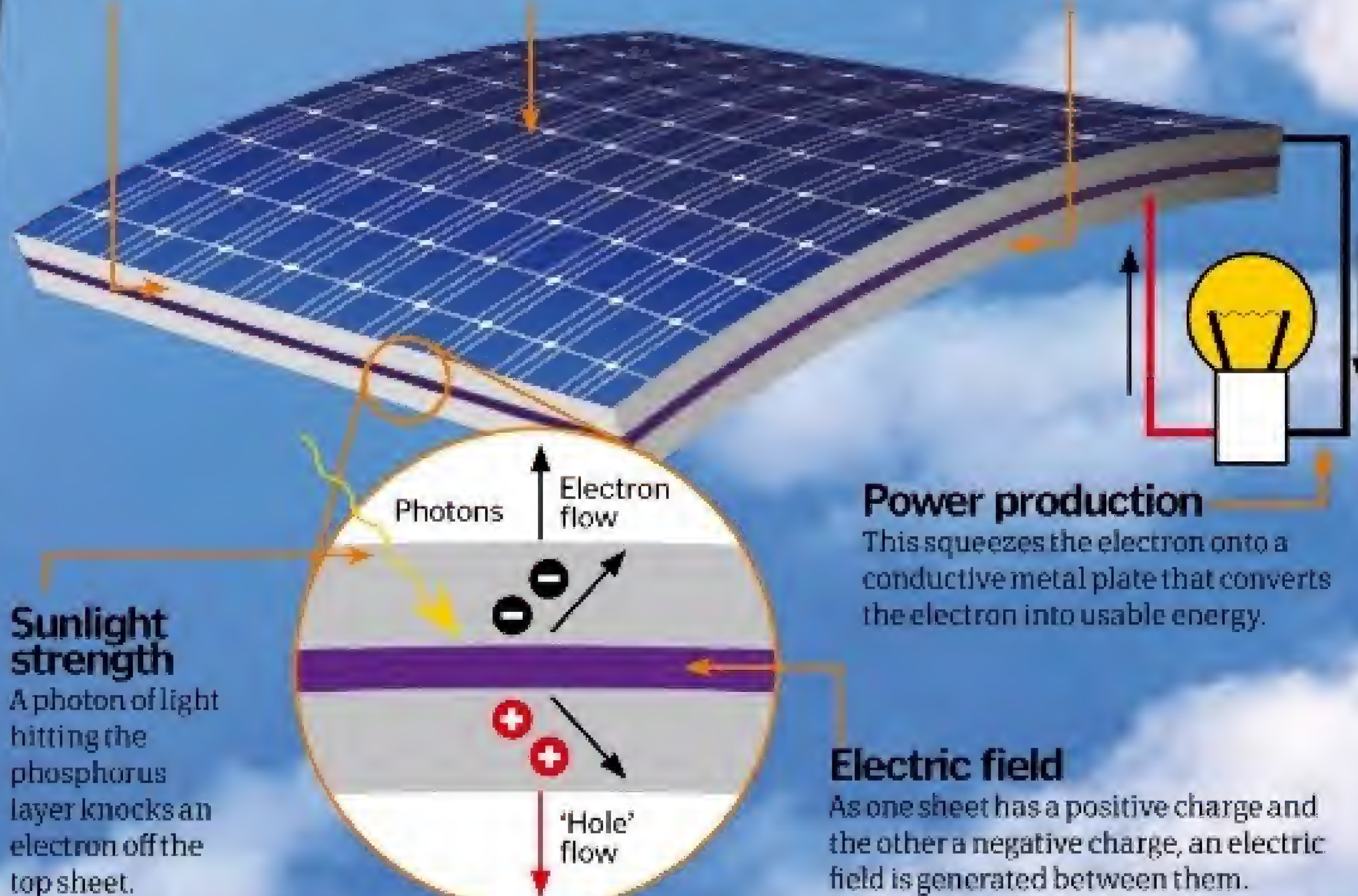
Solar-powered planes

How planes harness the Sun's energy

Silicon sandwich
A solar panel is made up of two sheets of silicon, split up into lots of photovoltaic cells.

Top layer
The top layer is coated with phosphorus, which increases the number of free electrons on that side.

Bottom layer
This layer will be coated with boron, which decreases the number of free electrons.



Power production
This squeezes the electron onto a conductive metal plate that converts the electron into usable energy.

Sunlight strength
A photon of light hitting the phosphorus layer knocks an electron off the top sheet.

Electric field
As one sheet has a positive charge and the other a negative charge, an electric field is generated between them.

SPACE PLANES

These out-of-this-world vehicles are boldly going where no commuter has gone before

Travelling faster than the speed of sound, Concorde made it from London to New York in around three hours. However, that's sloth-like compared to the space plane aiming to travel from Europe to Australia in half that time.

That craft is SpaceLiner, being developed the German Aerospace Center. This 83.5-metre (274-foot) long craft could carry up to 100 passengers up to 80 kilometres (50 miles) into the air, gliding in sub-orbit at over 20 times the speed of sound. It would be delivered into the higher layers of our atmosphere by LOX/LH_2 (liquid oxygen and liquid hydrogen) rockets before disengaging at nearly four kilometres (2.5 miles) per second. This would allow it to reach Australia from Europe in as little as 90 minutes from takeoff to landing.

Also on the horizon are the Virgin Galactic and Skylon space planes, which are looking to go directly up from – rather than around – the Earth. Virgin Galactic's SpaceShipTwo will be launched from a jet-powered plane. It will take passengers into space for a few minutes before returning to Earth. Skylon, on the other hand, is an unmanned, reusable space plane designed to carry 15 tonnes of cargo into outer space and return. This would make it much easier and cheaper for private companies to send cargo into space for use on satellites and space stations.

They used to say the sky's the limit, but the next generation of passenger and cargo planes have shown that it's only the beginning.

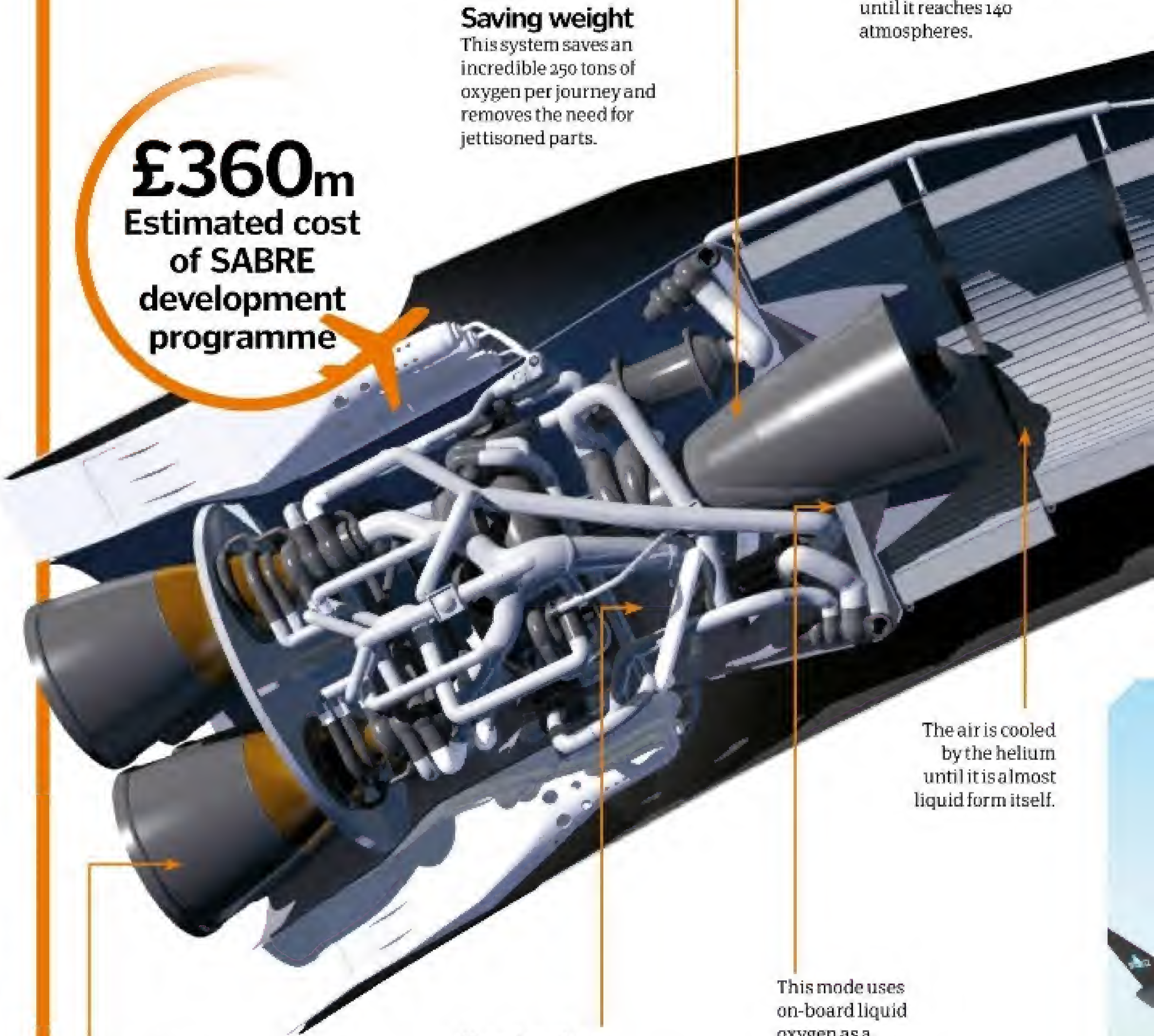
Design: Reaction Engines Ltd

SKYLON

Inside the SABRE engine

What is powering this new, reusable rocket Skylon?

£360m
Estimated cost of SABRE development programme



VIRGIN GALACTIC

Design: Scaled Composites

Richard Branson announced to the world in 2004 that he would be sending tourists into space, making Virgin Galactic the first commercial space plane. However, despite original plans to launch a flight in 2007, Virgin Galactic is yet to take its first batch of space tourists into the Solar System.

The ship will be carried to a height of 15,240 metres (50,000 feet) by the support craft WhiteKnightTwo. The crafts will detach and the passenger ship will fire its rockets to take its passengers out of the Earth's atmosphere and into space.

After four to five minutes it will re-enter the Earth's atmosphere, coming back to land on the runway at its New Mexico base.

The technical and logistical hitches that have set the programme back are being resolved, with the Federal Aviation Administration (FAA) clearance a major hurdle overcome in May 2014. Hopefully, the journey to outside our atmosphere is just around the corner.


The Virgin Galactic team standing in front of SpaceShipTwo

$250,000
Virgin Galactic ticket cost

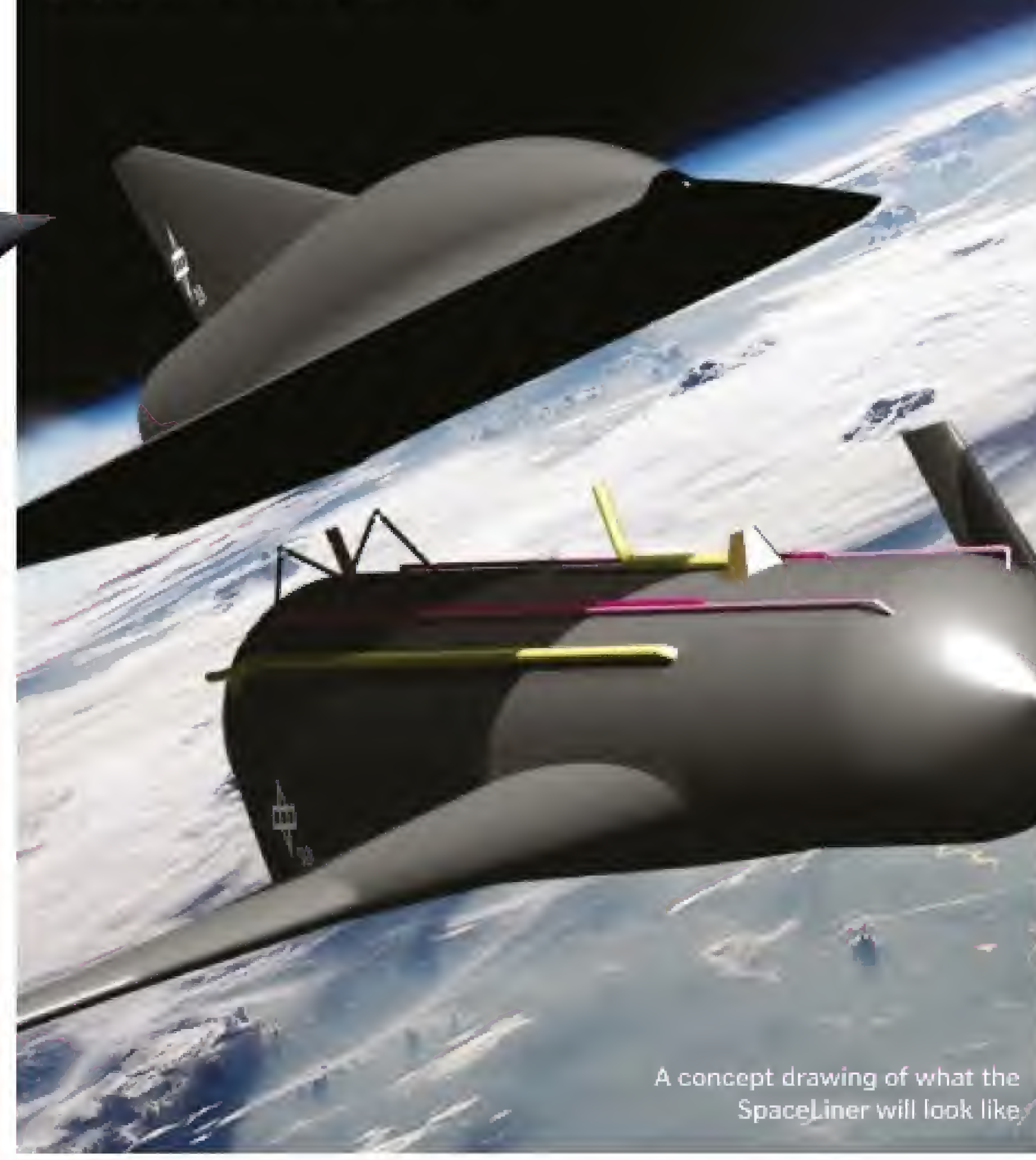
What the Skylon will look like when it soars above our skies


SpaceShipTwo has already flown several test flights


SpaceShipTwo has a hybrid-power rocket motor

SPACELINER

Design: German Aerospace Center


A concept drawing of what the SpaceLiner will look like

London to Sydney in 90 minutes

We spoke to Olga Trivailo who works at the German Aerospace Center to explain what is in store for future long-distance fliers

How exactly will the proposed SpaceLiner work?
It will use standard rocket technology such as liquid hydrogen and oxygen-fuelled rockets to accelerate to Mach 25. Once it is at 70 to 80 kilometres (43.5 to 50 miles) high, the booster will detach and return to the launch site. The craft will then glide all the way to its destination.

Does the lack of gravity or wind resistance play a part in its speed?
No. It cuts travelling times so much purely because it is travelling so fast from the rocket boost. It needs to go that high to go that fast so it can get the full benefit from the rocket's speed.

What sets the SpaceLiner apart from other flight options?
The reusability is a major part in the SpaceLiner programme. The fact that we will be able to reuse both parts of the rocket makes it much more viable as a business.

What kind of market are you looking at then?
Initially we want to target the business-class passengers who need to travel long distances and want to cut down their time. A trip to Australia from Europe [currently] takes over 24 hours when you count transfer time and when you get there, you just don't feel human. I feel this will really benefit mankind as SpaceLiner could also be used to transport time-sensitive cargo, such as organs.

Will everyone be able to use it, or just the extremely physically fit?
Anyone who is reasonably healthy can travel on it. At take-off you would experience at most 2.5 g. To put this into perspective, a normal flight could create up to 1.25 g and some roller coasters experience 5 g.

When are we expecting it to come into service?
If we're being realistic, in around 30 to 35 years. We need that time because, even though the rocket technology is there, we need to make it safe for the public to use. This means finding materials that can deal with the heat of the Earth's atmosphere and making the passenger pod capable of turning into an emergency escape pod in the unlikely event of an accident.

Boeing 787 Dreamliner

This jetliner has transformed the commercial airliner industry, boasting significantly improved fuel economy and a host of next-gen features. We take a closer look…

At first glance the Boeing 787 Dreamliner appears to be nothing special. A new mid-sized jetliner that through its conventional design, standard power output and modest maximum range seems to, for the most part, blend in with the crowd. Just another commercial passenger jet introduced to a market hit severely by the worldwide recession. A multimillion pound piece of technology that changes nothing. But if you believe that, then you couldn't be more wrong…

That is because, as is common with most groundbreaking new technologies and ideas, the devil is in the details. Indeed, the 787 is arguably a slice of the future today, both literally (its service life is predicted to extend up to 2028) and metaphorically. The latter comes courtesy of it being the first aircraft to be designed within a mantra of efficiency over all else. That's not to downplay its numerous improvements and technological advancements in any way – this is one of the most complex jetliners currently in operation – but in the present financial climate and arguably one that will affect the industry for years to come, this greener, cheaper and more accommodating aircraft is laying down a roadmap that others can follow. The evidence for this? How about worldwide orders of 982 planes from 58 operators to the tune of over £100 ($169) billion?

So how is the 787 turning the dream of cheaper, more efficient air travel into a reality? The simple answer is a direct 20 per cent saving on both fuel usage and outputted emissions. The long answer is a little more complicated.

The key to the super-high performance granted by the Dreamliner lies in its adoption of a suite of new technologies and materials. Composite materials (ie carbon-fibre/reinforced carbon-fibre plastics) make up 50 per cent of the primary structure of the 787, which include both the fuselage and the wings. These are lighter, stronger and more versatile than traditional pure-metal offerings. Indeed, when this model is compared against the Dreamliner's predecessor, the 777 – read: a mere 12 per cent composite materials and over 50 per cent aluminium – you begin to grasp what a game-changer this vehicle is to the jetliner industry.

The new materials have been partnered with a completely revisited build process, which allows each Dreamliner to be produced from fewer aluminium sheets, less fasteners (an 80 per cent reduction on the 777) and simpler drill schematics – the latter allowing a 787 to have fewer than 10,000 holes drilled in its fuselage (the 747 needed over 1 million). This saves on production costs, assembly time and streamlines the build, reducing potential points of failure, while increasing aerodynamic efficiency. In addition, more than 60 miles of copper wiring has been eliminated from the new model, again saving weight, plus streamlining the electrical

© Boeing


More than 50 companies have worked on the 787, each connected virtually at 135 sites worldwide
© Boeing


787 cabin layouts can be split into one of three configurations, prioritising capacity or class divisions
© Boeing

infrastructure. Talking of electronics, the Dreamliner has been designed with a state-of-the-art, fully electronic architecture, which through the replacement of all bleed air and hydraulic power sources with electrically powered compressors and pumps, extracts as much as 35 per cent less power from its engines at any one time. Further, a new electrothermal wing ice protection system – with moderate heater mats located on wing slats – improves de-icing levels and consistency significantly, again boosting aerodynamic performance. Wing lift performance is also improved thanks to the adoption of raked wingtips, which reduce the thrust needed by the engines.

These efficiencies combine with the heart of the Dreamliner: its twin next-generation, high-bypass turbofan engines. Two engine models are used on the 787 – both the General Electric GEnx and Rolls-Royce Trent 1000 – each delivering a maximum thrust of 280 kilonewtons (64,000 pounds force) and a cruise speed of Mach 0.85 (1,041 kilometres/647 miles per hour). Both engines are designed with lightweight composite blades, a swept-back fan and small-diameter hub to maximise airflow and high-pressure ratio – the latter, when complemented by contra-rotating spools, improving efficiency significantly. Finally, both engines are compatible with the Dreamliner's noise-reducing nacelles, duct covers and air-inlets. Indeed, the engines are so advanced that they are considered to be a two-generation improvement over any other commercial passenger jet.

As such, contrary to initial appearances, the Dreamliner is really a wolf in sheep's clothing, delivering standard-bearing improvements, along with a vast list of incremental ones – including energy-saving LED-only lighting – that make it one of the most advanced and future-proofed jets in our skies today. And you know what is most exciting? Judging by Boeing's current substantial backlog of sales, there is a high probability that you will be flying on one of these mighty machines yourself in the very-near future.

The statistics...

Boeing 787 Dreamliner

Crew: 2

Length: 57m (186ft)

Wingspan: 60m (197ft)

Height: 17m (56ft)

Max weight: 228,000kg (502,500lb)

Cruise speed: 1,041km/h (647mph)

Max range: 15,200km (9,440mi)

Max altitude: 13,100m (43,000ft)

Powerplant: 2 x General Electric GEnx / Rolls-Royce Trent 1000


A General Electric GEnx high-bypass turbofan jet engine, one of two used on the Dreamliner
© Oliver Cleynen

Anatomy of the Dreamliner

Breaking down a Boeing 787 to see how it outpaces, out-specs and outmanoeuvres the competition

© Boeing


© Boeing

Cockpit

The Dreamliner's state-of-the-art cockpit is fitted with Honeywell and Rockwell Collins avionics, which include a dual heads-up guidance system. The electrical power conversion system and standby flight display is supplied by Thales and an avionics full-duplex switched ethernet (AFDX) connection transmits data between the flight deck and aircraft systems.

Cargo bay

The standard 787 – referred to as the 787-8 – has a cargo bay capacity of 125m³ (4,400ft³) and a max takeoff weight of 227,930kg (503,000lb). The larger variant – referred to as the 787-9 – has a cargo bay capacity of 153m³ (5,400ft³) and a max takeoff weight of 247,208kg (545,000lb).

Electronics

The 787 features a host of LCD multifunction displays throughout the flight deck. In addition, passengers have access to an entertainment system based on the Android OS, with Panasonic-built touchscreen displays delivering music, movies and television in-flight.


The first completed Dreamliner was delivered to All Nippon Airways in 2011

© Boeing

Flight systems

The 787 replaces all bleed air and hydraulic power sources with electrically powered compressors and pumps. It is also installed with a new wing ice protection system that uses electrothermal heater mats on its wing slats to mitigate ice buildup. An automatic gust alleviation system reduces the effects of turbulence too.

Wings

The 787 Dreamliner's wings are manufactured by Mitsubishi Heavy Industries in Japan and feature raked wingtips. The raked tips' primary purpose is to improve climb performance and, as a direct consequence, fuel economy.

Engines

Two engine models are compatible with the Dreamliner: twin General Electric GEnx or Rolls-Royce Trent turbofans. Both models produce 280kN (64,000lbf) and grant the 787 a cruising speed of 1,041km/h (647mph). They are also compatible with the jet's noise-reducing nacelles, duct covers and exhaust rims.

Evolution of the jetliner

We select some of the high points in the development of the commercial jetliner

1945 Vickers VC.1 Viking
A British short-range airliner derived from the Wellington bomber, the Viking was the first pure jet transport aircraft.

1952 DH-106 Comet
The Comet was the world's first commercial jet airliner to reach production. It was developed by the de Havilland company in England.

1955 SE-210 Caravelle
The most successful first-generation jetliner, the Caravelle was sold en masse throughout Europe and America. It was built by French company Sud Aviation.

1958 Boeing 707-120
The first production model of the now-widespread 707 series, the 707-120 set a new benchmark for passenger aircraft.

1961 Convair 990
A good example of a narrow-body jetliner, the 990 offered faster speeds and greater passenger-holding capacity.

1976 Aérospatiale-BAC Concorde
A standout development in the second generation of jetliners, the Concorde delivered supersonic, transatlantic flight – something unrivalled even to this day.

© Boeing

A stand-up, fully stocked bar is available on each 787

Cabin
The standard 787 is designed to seat 242 passengers across a three-class arrangement, with 182 seats in economy, 44 seats in business and 16 seats in first. Cabin interior width rests at 5.5m (18ft) and on either side is lined with a series of 27 x 47cm (11 x 19in) auto-dimming windows.

Amenities
When on board passengers are offered roomier seats (across all classes), larger storage bins, manually dimmable windows, a stand-up bar, gender-specific lavatories and an on-demand entertainment system. First-class passengers receive a complimentary in-flight meal and, on international flights, fully reclinable seats for sleeping.

Fuselage
The 787 is constructed from 80 per cent composite materials (carbon fibre and carbon-fibre reinforced plastic) by volume. In terms of weight, 50 per cent of the materials are composite, 20 per cent aluminium, 15 per cent titanium, 10 per cent steel and 5 per cent other.

© Boeing

Compatibility
The 787 Dreamliner is designed to be compatible with existing airport layout and taxiing setups. As such the 787 has an effective steering angle of 65 degrees, allowing it to rotate fully within a 42m (138ft)-wide runway. It also has a 32m (100ft) tyre edge-to-turn centre ratio.

1986 Fokker 100
The Fokker 100 was a short-haul specialist that carried up to 100 passengers. Domestic and short-range international flights were its remit.

1994 Boeing 777
The first computer-designed commercial jetliner, the 777 delivered a vast 300-seat capacity and range (17, 370km/10,793mi). It became a mainstay of airlines worldwide.

2005 Airbus A380
Since its launch in 2005 the Airbus has been the largest passenger aircraft in the world. The A380 has two decks and, when specced out for all economy-class seating, can carry 853 passengers.

2011 Boeing 787 Dreamliner
The most fuel-efficient jetliner of its class, the 787 has been designed to reduce the cost of air travel, while delivering a range of next-gen tech.

© Boeing

Train to gain

Boeing has gone the extra mile to produce a complete package with the 787 Dreamliner, offering state-of-the-art simulation facilities for pilots to get up to speed

Potential 787 pilots can utilise Boeing's revolutionary full-flight simulator to train for real-world flights and specific context-sensitive scenarios. Currently there are eight 787 training suites at five Boeing campuses worldwide, located from Seattle through to Tokyo, Singapore, Shanghai and on to London Gatwick. The simulators, which are produced by French electronic systems company Thales, include dual heads-up displays (HUDs) and electronic flight bags (EFBs), and are designed to train pilots to become proficient in visual manoeuvres, the instrument landing system (ILS) and non-ILS approaches. Further, missed approaches using integrated specialist navigation, non-standard procedures with emphasis on those affecting handling characteristics, plus wind shear and rejected takeoff training can also be undertaken.

All of the training simulators are approved by the US Federal Aviation Administration (FAA), making them officially some of the most advanced training suites around right now.

Pilots and potential pilots can train at eight simulators worldwide

Solar-powered aircraft

The flying machines that are fuelled only by the Sun

As the search for renewable and carbon-neutral forms of energy intensifies, solar energy is leading the way for aircraft. One aircraft soaring through boundaries is the Solar Impulse 2. This incredible machine has just finished a non-stop round-the-world trip powered only by the Sun. It used its 72-metre- (236-foot-) wide wings, each of which carrying over 8,500 solar cells, which were used to power four electric motors and four lithium batteries. Despite this astonishing wingspan, the entire aircraft only weighs 2,300 kilograms (5,071 pounds).

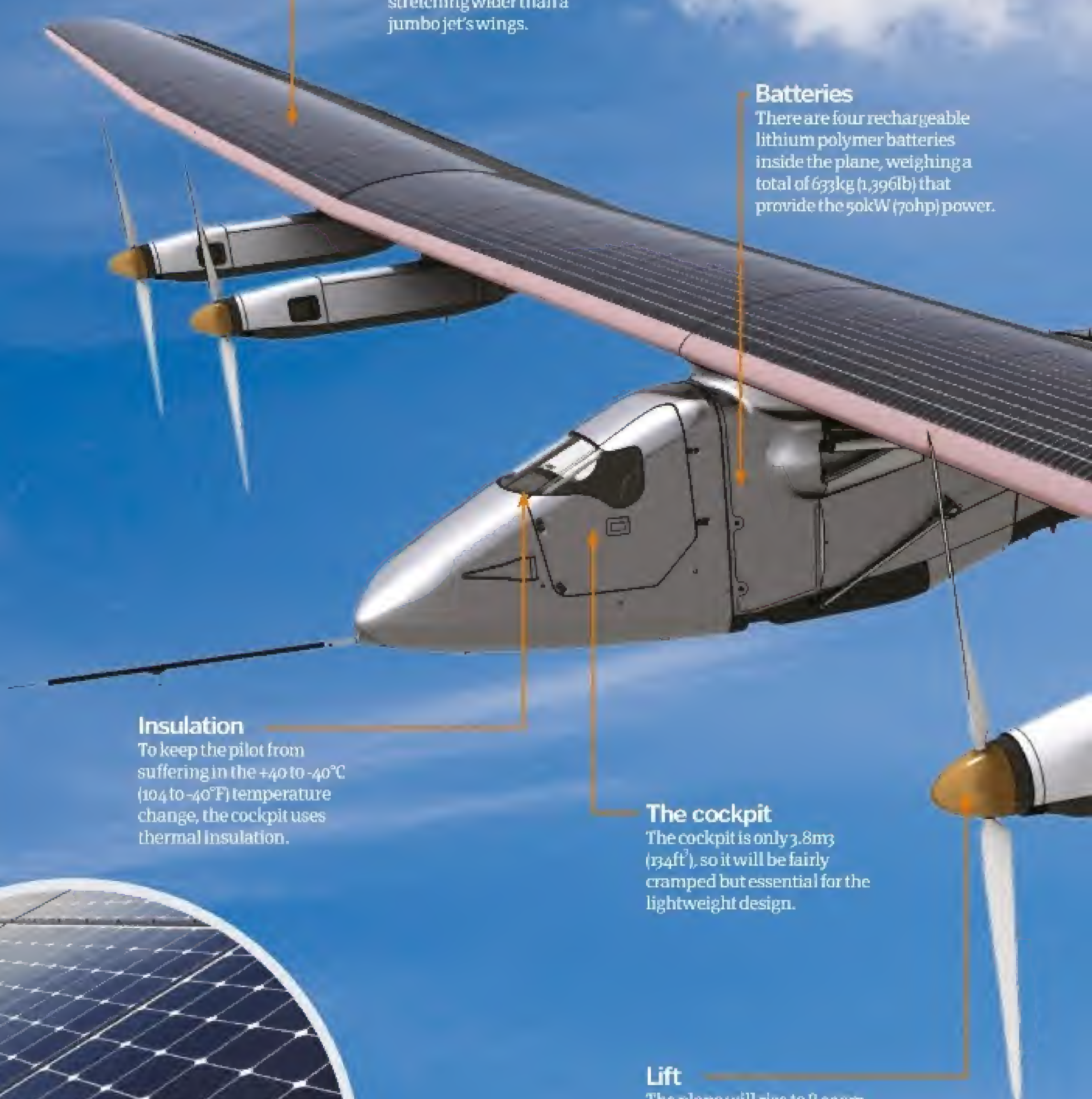
Another major player in the world of solar powered aviation is Solar Flight. Their newest project is Sunseeker Duo, which is the only two-seater solar-powered aeroplane in operation. It follows a similar pattern to the Solar Impulse 2, with long wings covered with solar panels and a lightweight body. Its panels have been improved to become 50 per cent more efficient than their predecessors. It can fly for 12 hours and its engine produces 25 kilowatts (33.5 horsepower) of power.

The main question with using solar power is 'what happens at night?' During the day, not all the energy is used. Enough will be stored in the batteries to allow the aircraft fly at night.

The Solar Impulse 2 landed successfully on 3 July 2015, and marked a huge achievement for alternative energy. The next challenge for solar-powered aviation is to be able to carry multiple passengers, so hopefully one day tourists can use the Sun on their way to soaking it up.

Anatomy of a solar aircraft

How the Solar Impulse 2 gets off the ground and stays there



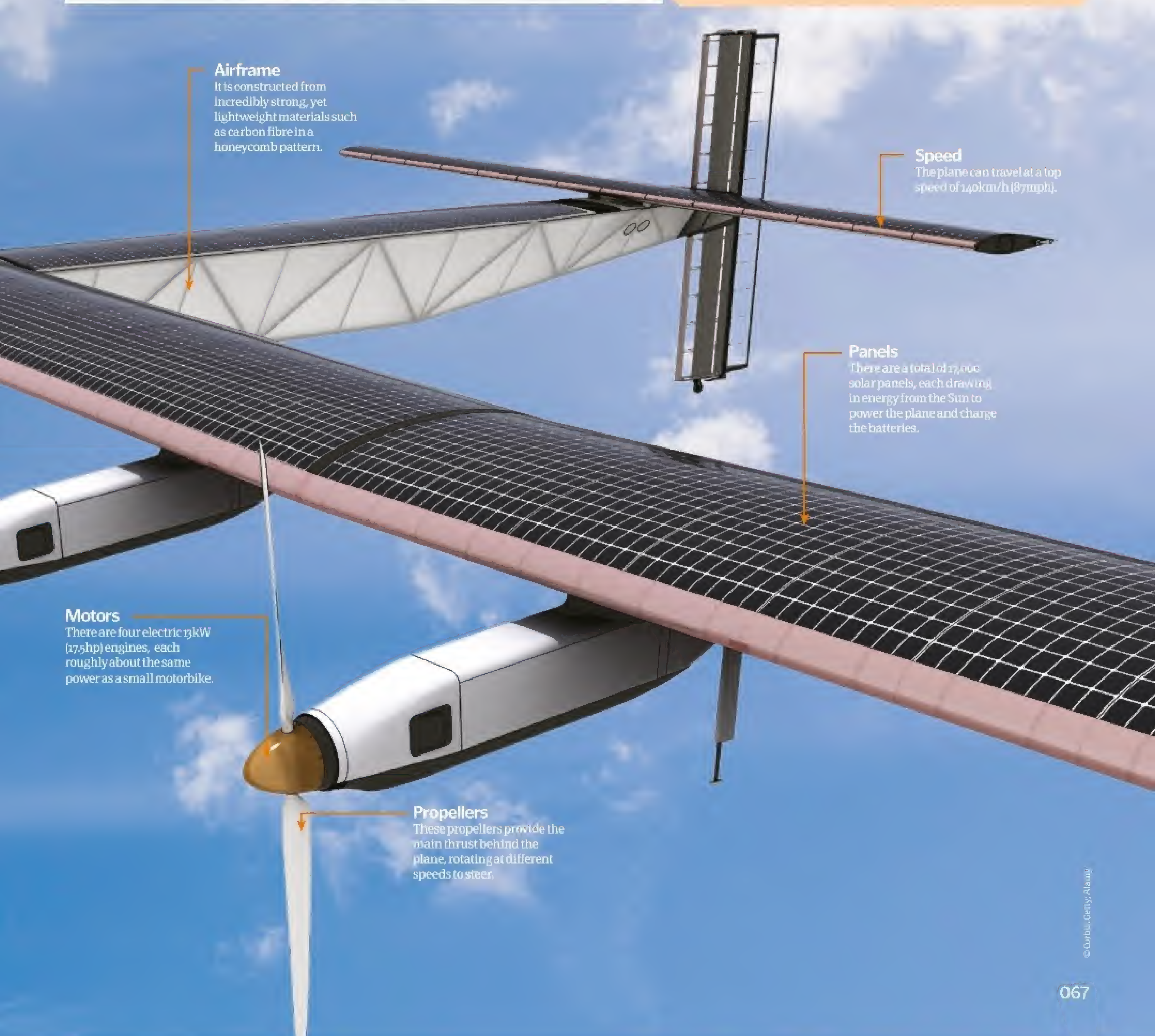
How solar panels work

How exactly do solar panels convert sunlight to energy? Inside a solar panel is a number of silicon cells, placed on top of each other. One of the silicon atoms has all its electrons, while the one beneath it has a few missing. In order to restore the balance, the full silicon atom transfers electrons to the one below, but it needs light to trigger the process. Once the sunlight hits the panel, electrons are transferred from one silicon cell to the other, thus creating an electric current that powers a load.

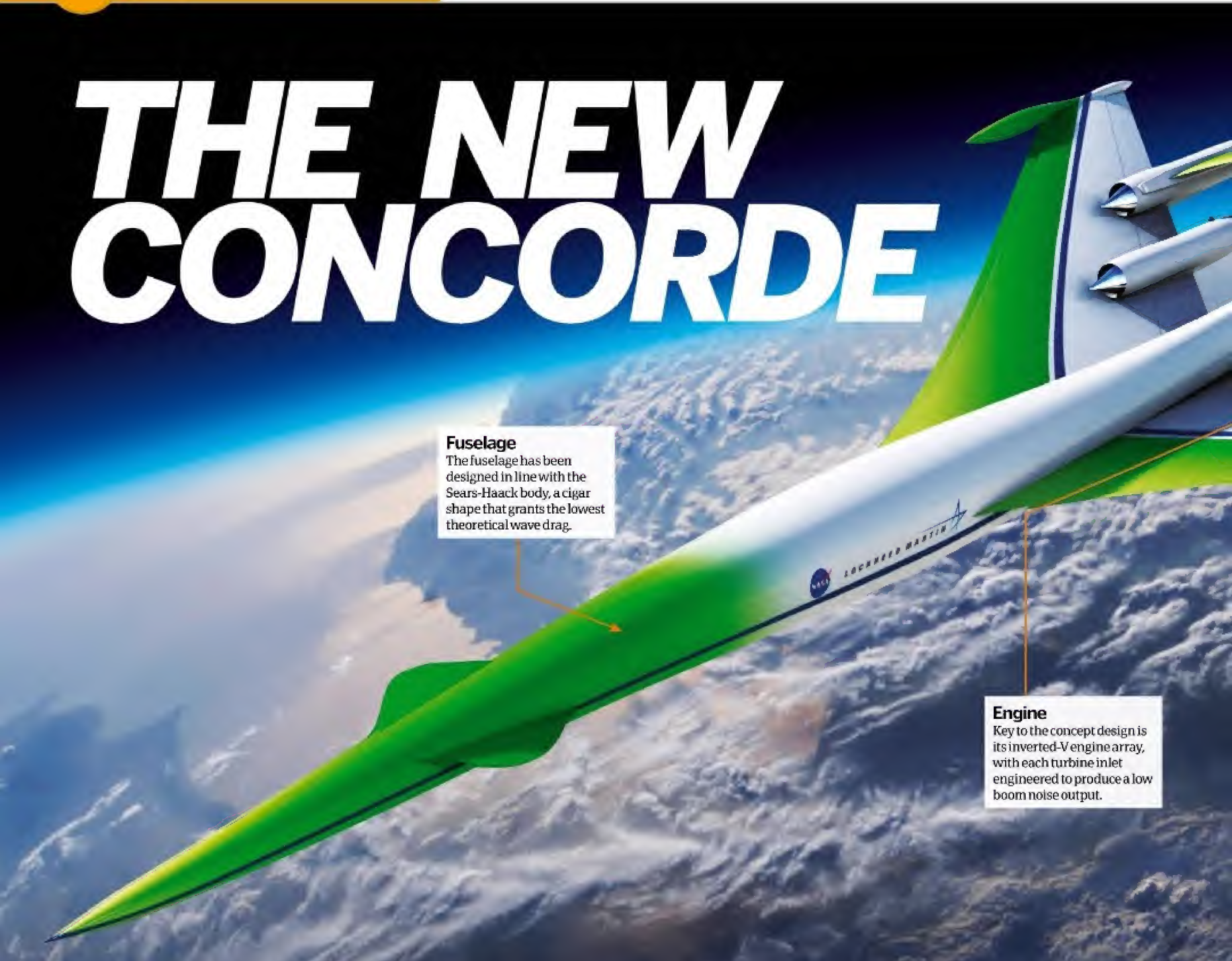
Despite the massive wingspan, the Solar Impulse weighs about the same as two small cars

Close up power

ESA's Solar Orbiter will be getting a ridiculous boost of solar energy when it takes off in 2017 as its mission is to get closer to the Sun than any probe has before, in order to take incredible pictures of the star. With its 3.1-metre x 2.4-metre (10.2-foot x 7.9-foot) sunshield, this craft will travel just 42 million kilometres (26 million miles) away from the Sun to take high-resolution images and perform experiments. It has been rigorously tested, as it will experience temperatures ranging from 520 degrees Celsius (968 degrees Fahrenheit) to -170 degrees Celsius (-274 degrees Fahrenheit). Its aim is to help scientists lean more about the inner heliosphere and how solar activity affects it, answering questions about solar winds, coronal magnetic fields and solar eruptions.



THE NEW CONCORDE



Concorde's successors are now on the horizon, offering Mach-shattering speeds, alongside hugely reduced noise and fuel consumption compared to their famous forebear

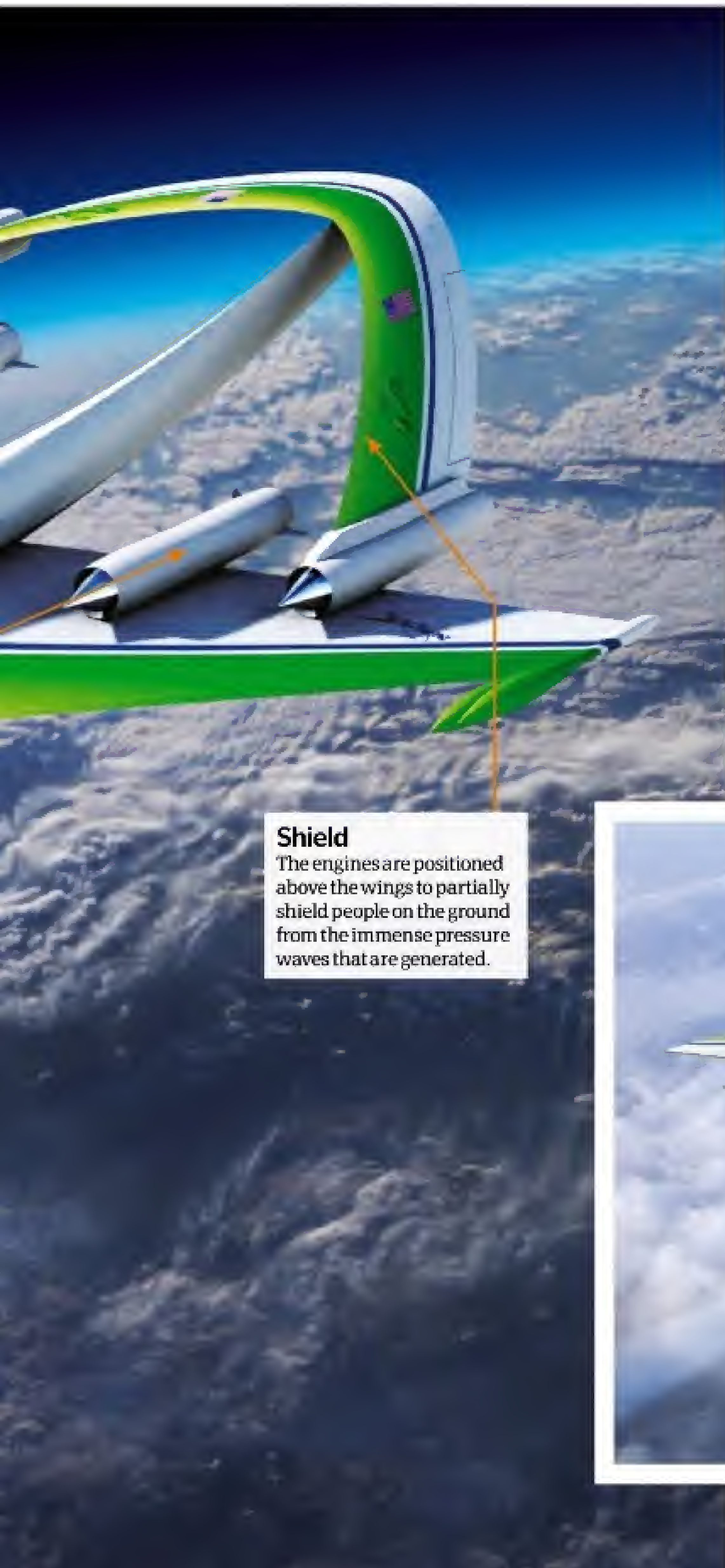
In 1976 we could fly commercially from London to New York in just three and a half hours. That's over 5,550 kilometres (3,460 miles) at an average speed of 27 kilometres (17 miles) per minute. For context, the same journey in a Mini Metro travelling continuously at 97 kilometres (60 miles) per hour would take close to 58 hours (almost two and a half days) – and that's not considering the fact a Mini can't fly!

Today, crossing the 'pond' – ie the Atlantic Ocean – takes more like seven and a half hours, a trip that definitely puts the 'long' into long-haul flight. So, this raises the question: what went wrong? A one-word answer is sufficient: Concorde. The Concorde supersonic jet, the piece of technology that allowed such outrageous flight times was retired for good back in 2003 after 27 years of service (for more information see the 'End of Concorde' boxout on p76). Further, no other supersonic jet has been introduced in its absence – leaving customers stuck travelling at subsonic speeds no matter where they wish to fly around the globe, and having to endure the longer flight times.

Things, however, are all about to change. Driven by the ever-growing notion of the global village – the interconnectedness of all nations – and fired by the gaping void left behind by Concorde, a new wave of supersonic jetliners have been put into production, aiming to pick up where Concorde touched down. The aim is to radically transform the speed, efficiency and impact of future commercial supersonic travel.

From Lockheed Martin's Green Machine concept (a supersonic jet capable of mitigating the effects of sonic boom) through Aerion Corporation's Supersonic Business Jet (a machine that introduces a radical new technology called natural laminar flow) and on to Boeing's Icon-II design (an aircraft that boasts far greater noise reduction and fuel efficiency) the future of this industry is already looking very exciting. For the first time, private companies are collaborating with the best research institutes in the world (one of which being NASA) to make supersonic flight a reality once more, outside of the military sphere that is.

Of course, while the roadmap to realisation is becoming more concrete with each passing day,



there are still major hurdles that need to be overcome – something driven by a call from NASA for companies to investigate ways to cancel out the damaging effects of sonic booms, increase fuel efficiency and improve the ability of supersonic jets to break through the transonic envelope (see the 'Shattering Mach 1' boxout over the page). These factors represent just a few of the challenges of not only achieving supersonic flight, but also making it commercially viable where Concorde ultimately wasn't.

In this feature, we take a much closer look at the science of travelling at supersonic speeds as well as at some of the aircraft and advanced technology currently leading the charge against Earth's sound barrier.

The Supersonic Green Machine

Lockheed Martin's Green Machine passenger plane offers a glimpse into the future of high-speed, eco-minded air travel

Lockheed Martin's Supersonic Green Machine recently piqued interest at NASA thanks to its inverted-V engine array. The array, which sits above the wings, has been designed to mitigate the generation of sonic booms, the loud and distinctive cracking sound heard when an object passes through the sound barrier. The positioning of the engines is not just an aesthetic choice either, but a strategic one that harnesses the wing area to effectively shield portions of the ground against pressure waves, thereby reducing the audible noise and 'boom carpet' heard on the ground.

Interestingly, the design of this new aircraft has also been developed to get as close as possible to the ideal aerodynamic form for a supersonic jet, with the fuselage closely resembling the Sears-Haack model (a cigar shape that minimises the creation of wave drag). While no concrete specifications of the aircraft have been released, according to Lockheed Martin and NASA, which have run model-sized trials in wind tunnels, the jet would offer speeds comparable to Concorde, but with significant reductions in fuel burn and noise output.

The second design for the Green Machine, a next-gen supersonic jet created by Lockheed Martin

Banishing the boom

For the latest supersonic jets to become a reality, special technology is being designed to keep the noise down

Even when active, Concorde was prohibited from flying at supersonic speeds over the USA due to the impact of sonic booms. Indeed, the inability of Concorde to fly over the majority of habituated land meant it had to follow elongated and inefficient flight routes, greatly damaging its efficiency.

Eradicating these sonic booms is therefore key to any future supersonic jet being greenlit for production, with nations worldwide concerned with the 'boom carpet' (the avenue on a jet's flight path where sonic booms can be heard). Three key developments in this area have been the recent introduction of far thinner wings than Concorde, the repositioning of the engines above the wings – this effectively turns the wings into shields, diverting pressure waves away from the ground – and the creation of pressure-sculpting air inlets for the aircraft's turbines.

While no physical jet has yet to enter production, experimentation by US space agency NASA in 2011 into sonic booms confirmed that, if the new designs could adequately hide the engine outlets within a narrow fuselage, then almost all audible noise could be cancelled out.

2x © NASA; Lockheed Martin

Aerion SBJ

The SBJ supersonic plane will be able to cruise at Mach 1.6, taking passengers from Paris to NYC in just over four hours

Aerion Corporation is arguably at the cutting edge of supersonic flight research, with the company collaborating closely with NASA on developing the tech necessary to introduce its Supersonic Business Jet (SBJ), a piece of kit that will be able to take passengers anywhere at over 1,900 kilometres (1,200 miles) per hour.

This ability will come courtesy of the advanced research into a technology called natural laminar flow (NLF). Laminar flow is the condition in which air in a thin region adjacent to a plane's wings stays in smoothly shearing layers, rather than becoming turbulent. This means that the more laminar the airflow, the less aerodynamic friction drag impinges on the wings, which improves both range and fuel economy.

This is possible due to the tapered bi-convex wing design, which is constructed from carbon epoxy and coated with a titanium leading edge. The partnering of this with the SBJ's aluminium composite fuselage delivers an aircraft that not only provides a range of over 7,400 kilometres (4,600 miles) and a maximum altitude of 15,544 metres (51,000 feet), but an aircraft that can do all this while sufficiently reducing fuel burn and therefore operating costs. The latter point is incredibly important as it was a primary factor that led to Concorde being scrapped.

The SBJ will be able to travel from New York to Paris in four hours and 15 minutes, almost half the time of a regular jetliner

The SBJ's cabin measures 9.1m (30ft) and allows for three dedicated seating areas

The statistics...

Aerion SBJ

Length: 45.2m (148.3ft)
Width: 19.5m (64.2ft)
Height: 7.1m (23.3ft)
Weight: 20,457kg (45,100lb)
Wing area: 111.5m² (1,200ft²)
Engines: 2 x PW JT8D-200
Max speed: Mach 1.6 (1,960km/h; 1,218mph)
Max range: 7,407km (4,603mi)
Max altitude: 15,544m (51,000ft)

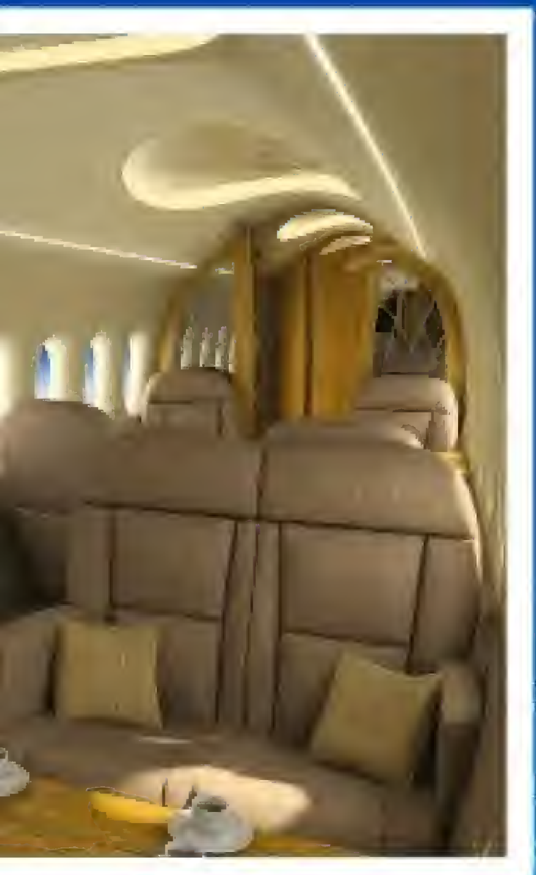
The end of Concorde

Concorde was an engineering masterstroke. So why did the luxurious jetliner get shut down?

What was arguably the death knell for Concorde was the disastrous crash of Air France's Flight 4590 in 2000, which killed all 100 of its passengers, nine crew members and four people on the ground. The crash was caused by a titanium strip falling off a Continental Airlines DC-10 aircraft that had taken off minutes before the ill-fated Concorde. The strip pierced one of Flight 4590's tyres, caused it to explode and consequently sent rubber into one of the aircraft's fuel tanks. The resultant shockwave caused a major fuel leak, which then ignited due to electrical landing gear wires sparking.

Post-crash, despite Concorde being arguably one of the safest operational passenger airliners in the world, both Air France and British Airways – its only two operators – reported a steep decline in passenger numbers, leading both fleets to be decommissioned in 2003.

A British Airways Concorde taking off shortly before the jetliner's retirement



Shattering Mach 1

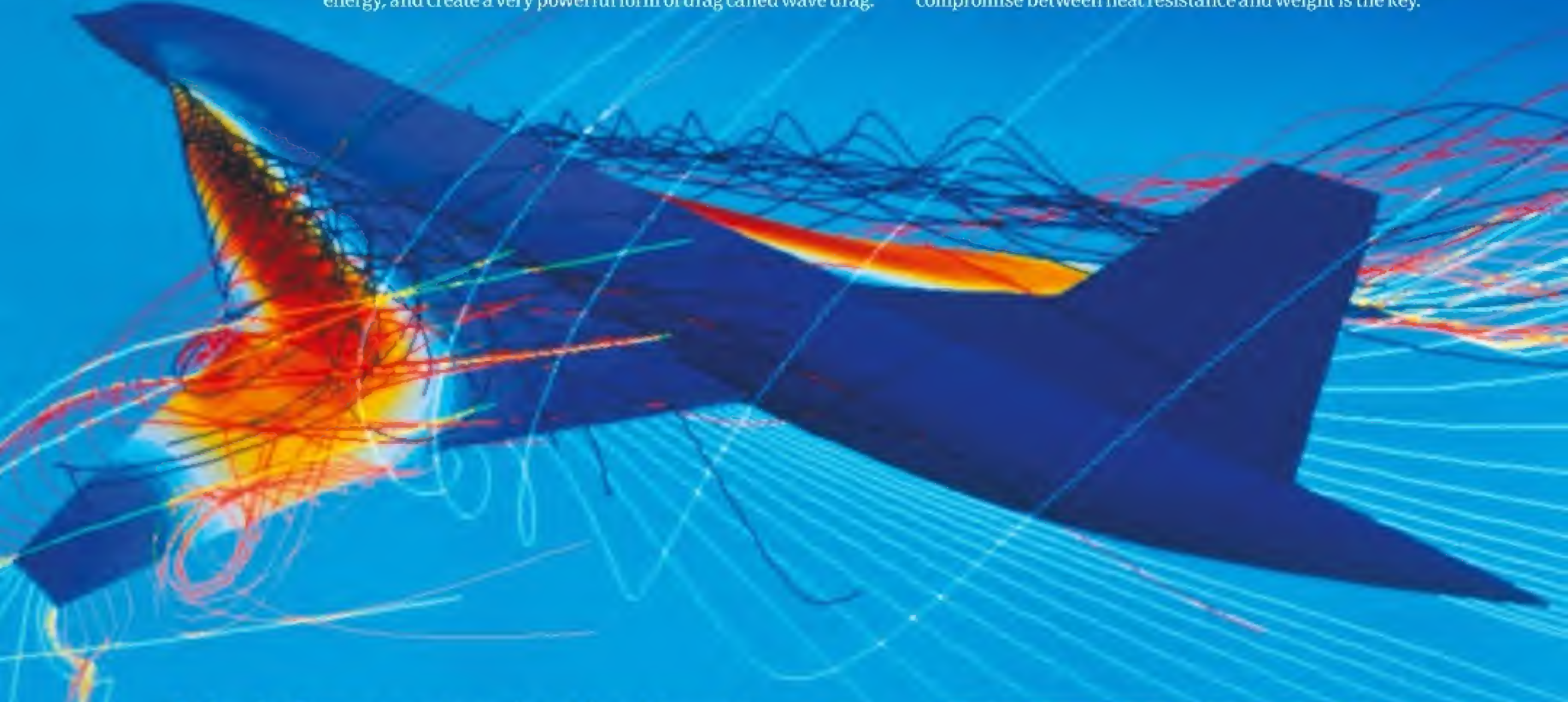
There is far more to creating a supersonic aircraft than simply strapping larger engines to a subsonic fuselage…

Supersonic aerodynamics are much more complex than subsonic aerodynamics for a variety of reasons, the foremost being breaking through the transonic envelope (around Mach 0.85-1.2). This is because to pass through this speed range supersonic jets require several times greater thrust to counteract the extreme drag, a factor that raises two key issues: shockwaves and heat.

Shockwaves come from the passage of air (with positive, negative or normal pressures) around the fuselage, with each part of the aircraft affecting its progress. As such, while air is bent around the thin fuselage with minimal effect, as it reaches the wings – a huge change in the cross-sectional area of the jet – it causes shockwaves along the plane's body. The resulting waves formed at these points bleed away a considerable amount of energy, and create a very powerful form of drag called wave drag.

To mitigate this, any supersonic jet design must allow for a smooth-as-possible change in cross-sectional areas, with the wings fluidly curving out from the fuselage.

Heat is the other big concern. Sustained supersonic flight – as a by-product of the drag it generates – causes all of its materials to experience rapid and prolonged heat, with individual parts sometimes reaching in excess of 300 degrees Celsius (572 degrees Fahrenheit). As such, conventional subsonic materials like duraluminium (or dural) are infeasible for a supersonic jet, as they experience plastic deformation at high temperatures. To counter this, harder, heat-resistant materials such as titanium and stainless steel are called for. However, in many cases these can push up the overall weight of the aircraft, so reaching a workable compromise between heat resistance and weight is the key.



This shows the airflow over a supersonic jet's surface (including turbulence over the wing). The colour of the lines shows the air speed from red (fastest) to blue (slowest). In addition, the fuselage colour indicates its temperature, from blue (coolest) to red (hottest). Supersonic jet fuselages can be heated to over 100°C (212°F) by air friction

Sonic boom science

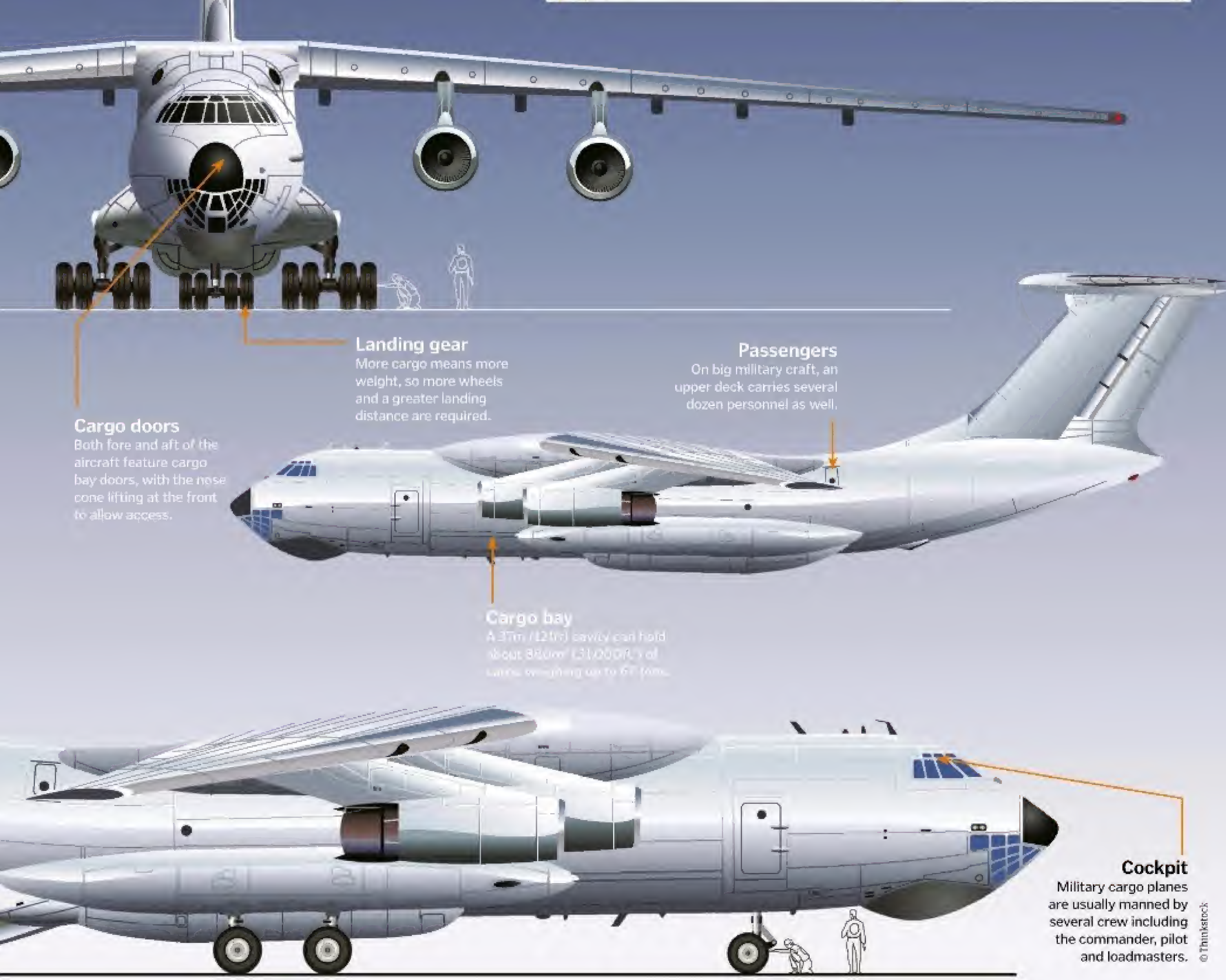
What are sonic booms and how are they generated?

Sonic booms are caused as, when an object passes through the air, it generates a series of pressure waves. These pressure waves travel at the speed of sound and increase in compaction the closer the object is to Mach 1 – approximately 1,225 kilometres (761 miles) per hour. When an object is travelling at the speed of sound (ie Mach 1), however, the sound waves become so compressed that they form a single shockwave, which for aircraft, is then shaped into a Mach cone. The Mach cone has a region of high pressure at its tip – before the nose of the aircraft – and a negative pressure at its tail, with air pressure behind the cone normal. As the aeroplane passes through these varying areas of pressure, the sudden changes create two distinctive 'booms': one for the high-to-low pressure shift and another for the low-to-normal transition.

Streams of dye are used to show the flow of water over the surface of a supersonic jet. The flow of water over the surface of the fuselage indicates what the airflow would be like over a full-sized aircraft

2x © SPL


Lockheed Martin's C-5 Galaxy has 12 internal wing tanks with a total capacity of 194,370l of fuel


Landing gear
More cargo means more weight, so more wheels and a greater landing distance are required.
Passengers
On big military craft, an upper deck carries several dozen personnel as well.
Cargo doors
Both fore and aft of the aircraft feature cargo bay doors, with the nose cone lifting at the front to allow access.
Cargo bay
A 37m (124ft) cavity can hold about 880m³ (31,000ft³) of cargo weighing up to 67 tons.
Cockpit
Military cargo planes are usually manned by several crew including the commander, pilot and loadmasters.

1. Wings
Through the Harrier's compact wings run a series of exhaust tubes that allow high-pressure air to be filtered from the engine to its tips, increasing stability during manoeuvres.

2. Nozzles
One of the Harrier's Pegasus engine vectoring nozzles. Through these four nozzles – which can be rotated through a 98.5-degree arc – the engine's thrust can be directed for vertical or short take-off.

VTOL aircraft

For the past 60 years, Vertical Take-Off and Landing (VTOL) aircraft have evolved massively as engineers have strived for what can be argued to be the Holy Grail of aeronautics

Harrier Jump Jet

The most famous of all VTOL aircraft, the Harrier fighter jet is utilised all over the world thanks to its advanced technology and aerodynamic versatility

For the past 40 years, since its introduction in 1969, the Harrier Jump Jet has epitomised the vertical take-off and landing concept. Born amid a fervent arms race to produce a light attack, multi-role fighter with VTOL capabilities, the Harrier proved that VTOL could work in reality, advancing the vastly expensive and solely academic efforts that had been designed previously. Indeed, to this day it is still in operation world wide, and praised for its versatility and reliability.

The Harrier's VTOL capabilities are made possible by its Rolls-Royce Pegasus engine, a low bypass-ratio turbofan that features four rotating nozzles through which its fan and core airflows exhaust. These nozzles can be rotated by the pilot through a 98.5-degree arc, from the conventional aft (horizontal) positioning as standard on aircraft, to straight down,

3. Air intakes
Central to the Harrier's VTOL capabilities is the distribution by its engine of high-pressure air across all of its multi-directional nozzles. This air is drawn in through the Harrier's dual air intakes.

Getting off the ground…

2. Thrust
The Pegasus engine evenly distributes the engine's massive thrust across the four main vector nozzles, providing lift and balance.

1. Stability
In partnership with the main vector nozzles, reaction control nozzles in the wing tips, nose and tail help maintain stability in the air.

3. Moving forward
Once requisite vertical thrust has been achieved, the Harrier's pilot then gradually rotates the vector nozzles to achieve forward momentum.

One of the rotatable vector nozzles necessary to lift the Harrier vertically

© Wyrdlight

A shot of the Rolls-Royce Pegasus engine that powers the Harrier

ON THE MAP

Harrier deployment
The Harrier is operated worldwide by many military organisations in the following countries:

1 UK
2 Spain
3 Italy
4 India
5 Thailand
6 USA

allowing it to take-off and land vertically as well as hover, to forward, allowing the Harrier to drift backwards. All nozzles are moved by a series of shafts and chain drives, which ensures that they operate in unison and the angle and thrust are determined in-cockpit by the pilot.

The control nozzle angle is determined by an additional lever positioned alongside the conventional throttle and includes fixed settings for vertical take-off (this setting ensures that true vertical positioning is maintained in relation to aircraft altitude), short-take off (useful on aircraft carriers) and various others, each tailored to aid the pilot's control of the Harrier in challenging flight conditions.

Of course, the nozzle lever can be incrementally altered too by the pilot, as in order to be able to fly the Harrier, fine control of the throttle in relation to the nozzle lever is central, adding an extra dimension to any potential pilot's training.

As well as the vectoring engine nozzles, the Harrier also requires additional reaction control nozzles in its nose (downward firing), wingtips (downward and upward firing) and tail (down and lateral firing) in order to remain stable once airborne. These nozzles are supplied with high-pressure air filtered from the engine and distributed through a system of pipes that run through the aircraft. Controlled through valves, this sourcing and utilisation of compressed air allows the pilot to adjust the Harrier's movement in pitch, roll or yaw.

This system is energised once the main engine nozzles are partially vectored and the amount of compressed air filtered to the anterior nozzles is determined by airspeed and altitude.

Vertol VZ-2

One of the first fully functional VTOL aircraft, the Boeing Vertol VZ-2 paved the way for the gargantuan V-22 Osprey

"The VZ-2 sported twin rotors powered from a single 700hp turboshaft engine"

Many VTOL aircraft have been designed in the past 50 years, however most fall into one of two categories; those based on vectoring engine nozzles, and those that adopt tilt-wing technology. The Vertol VZ-2 falls into the latter category and was a wildly experimental research aircraft built in 1957 to investigate the tiltwing approach to VTOL. Resembling a conventional helicopter, albeit with an extended plane-like T-tail, the VZ-2 had an uncovered tubular framework fuselage and a single-seater bubble canopy.

The VZ-2 sported twin rotors powered from a single 700hp turboshaft engine, which positioned on its rotatable wings, in partnership with a series of small ducted fans in the T-tail, provided thrust and lift. Due to its lightweight design, the maximum speed achieved was 210mph and it had a low operational service ceiling of 13,800ft as well as a minuscule range of 210km.

Despite these shortcomings, the Vertol proved a very successful and fruitful experiment as over its eight-year life span it made 450 flights, including 34 with full vertical to horizontal transitions. The heritage of the VZ-2 can be seen today in the titanic tilt-rotor design and technology used on the V-22 Osprey.

The first non-transition test flight of the VZ-2


© George Chmilevsky

The statistics...

Vertol VZ-2

Crew: 1
Length: 8.05m
Wingspan: 7.59m
Height: 4.57m
Weight: 3,700lb
Engine: 1x Avco Lycoming YT53-L Turboshaft

Bell X-14

An experimental fixed-wing aircraft, the X-14 pushed back the boundaries of VTOL technology

Unlike the Vertol VZ-2, Bell's X-14 experimental VTOL aircraft was crafted and designed to be as close to existing aeroplanes as possible, with it even being constructed from parts of other existing aircraft. Not only were its wings fixed but its engine was in the standard horizontal position and, with a top speed of 180 miles per hour and operational service ceiling of 20,000 feet, the X-14's design appeared conventional. However, the X-14 was one of the first VTOL aircraft to utilise the emerging concept of multi-directional engine thrust, relying on a system of movable vanes to control the direction of its engine's power.

Interestingly, after a couple of years of successful flights, the aircraft was delivered to the NASA Ames Research Center as – in addition to providing a great deal of data on VTOL flight – its control system was similar to the one proposed for the lunar module and it was deemed a worthy test vehicle for space training. Indeed, Neil Armstrong, the first man to walk on the moon, flew the X-14 as a lunar-landing trainer and it was continually used by NASA until 1981 (seeing a total of 25 pilots climb in and out of its cockpit) when it was retired from service.


The Bell X-14 on a demonstration flight

The statistics...

Bell X-14

Crew: 1
Length: 7.62m
Wingspan: 10.36m
Height: 2.40m
Weight: 3,100lb
Engine: 2x Armstrong Siddeley Viper 8 Turbojet


The X-14 being prepped on runway before a test flight

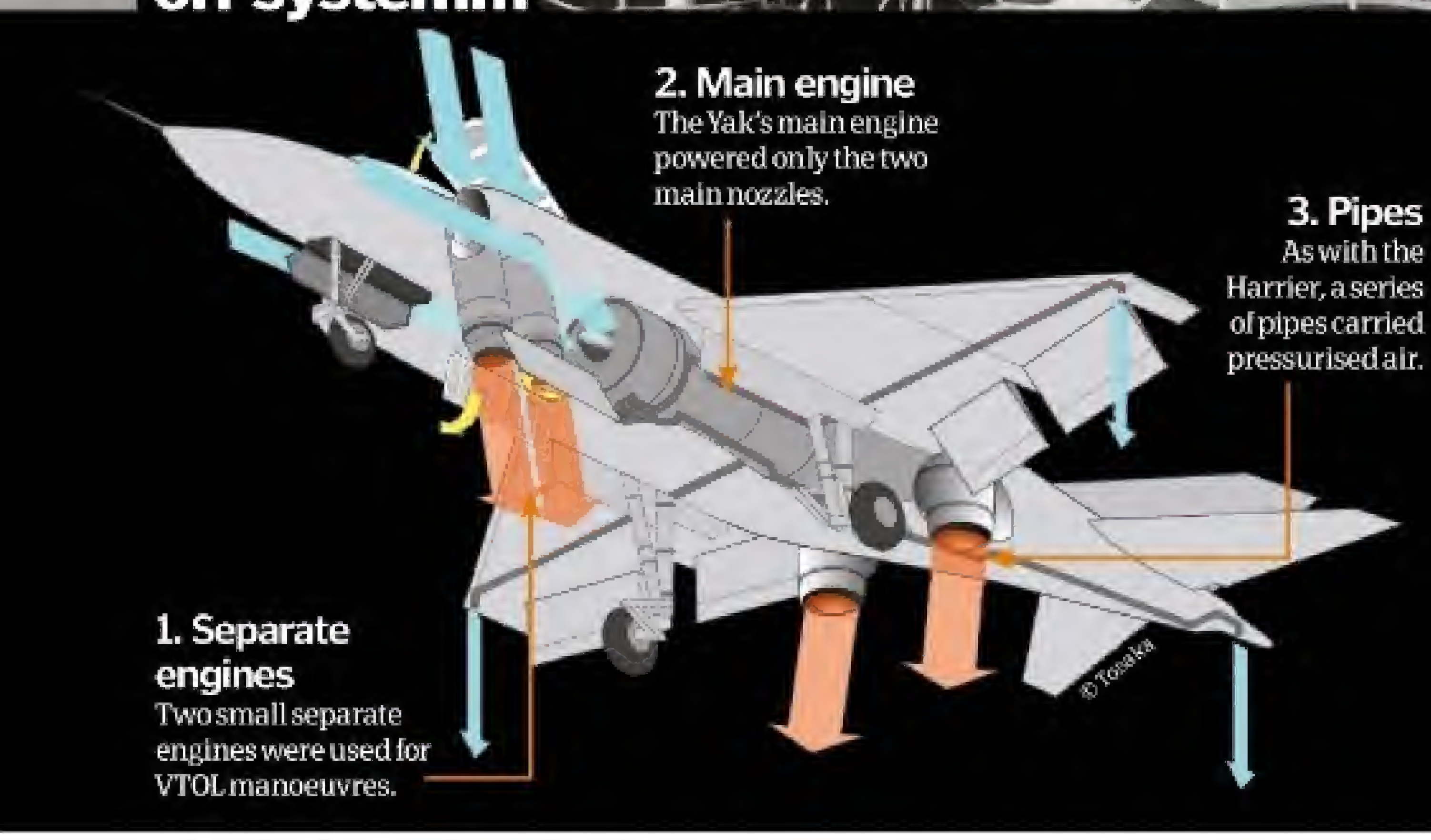
A Yak-38 on the deck of a Soviet aircraft carrier

The statistics...

Yak-38

Crew: 1
Length: 16.37m
Wingspan: 7.32m
Height: 4.25m
Weight: 16,281lb
Engine: 1x Tumansky R-28 V-300 Turbojet

Yak-38 take-off system...



2. Main engine
The Yak's main engine powered only the two main nozzles.

3. Pipes
As with the Harrier, a series of pipes carried pressurised air.

1. Separate engines
Two small separate engines were used for VTOL manoeuvres.

Yak-38

A retired variant of the Yak-38 with one of its vector nozzles clearly visible

© George Chernilevsky

The Soviet Naval Aviation's first and only foray into VTOL multi-role combat aircraft, the Yakovlev Yak-38

Influenced in design by the British Hawker P.1154 and Harrier Jump Jet, the Yak-38 VTOL aircraft looked similar to its contemporaries, but its radically different internal configuration and general poor quality build and systems turned out to be a costly mistake. Contrary to the Harrier's single Pegasus engine, where thrust was vectored through four nozzles from a single source, the Yak-38 featured only two nozzles from the main engine, relying on a pair of separate, less-powerful engines housed in the front portion of the aircraft to be used in conjunction for vertical take-off and landing.

Apart from being a less-refined and underdeveloped system, the Yak-38 was built en-masse; however, soon it encountered massive problems during sea trials. In hot weather the separate lift jets often failed to start (due to oxygen starvation), leaving it stranded on the flight deck and while it was initially deemed capable of carrying heavy payloads, the hot weather also reduced its operational range to such an extent that only extra fuel tanks could be carried. Further, the average engine life span of the aircraft was a minuscule 22 hours and many pilots encountered serious engine problems in every flight they undertook (over 20 Yak-38s crashed due to system/engine failure), with it quickly gaining a reputation as a killer. Finally, it was horrendously difficult to fly and could only be landed by remote telemetry/telecommand link, rendering it useless in land warfare.

Obviously, the Yak-38 did not live up to its conceptual ideal – a multi-mission 980km/h combat jet with VTOL capabilities, a service ceiling of 40,000ft and an operational range of 240km – and after a final deadly crash in June 1991 was retired out of service.

V-22 Osprey

The world's first tilt-rotor aircraft, the V-22 Osprey is at the cutting edge of VTOL technology

The pinnacle of tilt-rotor/wing VTOL aircraft, the V-22 has been in development for 30 years and offers the cargo carrying capabilities of a heavy lift helicopter, with the flight speed, altitude, endurance and range of a fixed-wing cargo plane.

This fantastic hybrid of two distinct forms of aircraft comes courtesy of its revolutionary tilt-rotor technology – twin-vectoring rotors that can be adjusted over 90 degrees by the pilot – which attached to foldable fixed-wings, allow for vertical take-off and then conventional flight. Both rotors are powered by Allison T406-AD400 tilt-rotor engines that – considering its massive size and carrying capacity (20,000 pounds internally) – develop 6,150hp each.

Interestingly, the V-22's design, despite being more accomplished at short take-off and landing (STOL) manoeuvres, loses out to tilt-wing VTOL aircraft – such as demonstrated in the Vertol VZ-2 – in VTOL manoeuvres by ten per cent in terms of vertical lift. However, due to the lengthy periods of time that the V-22 can maintain its rotors over 45 degrees, longevity of the aircraft is greatly improved.

Unfortunately, despite current safe and successful operation in the Iraq and Afghanistan conflicts, during testing numerous accidents occurred involving the V-22, resulting in over 30 deaths to crewmen and combat troops.

The V-22 broke new ground for VTOL aircraft

The statistics...

V-22 Osprey

Crew: 4
Length: 17.5m
Wingspan: 14m
Height: 6.73m
Weight: 33,140lb
Engine: 2x Rolls-Royce Allison T406/AE 1107C-Liberty Turboshaft

HOW IT WORKS

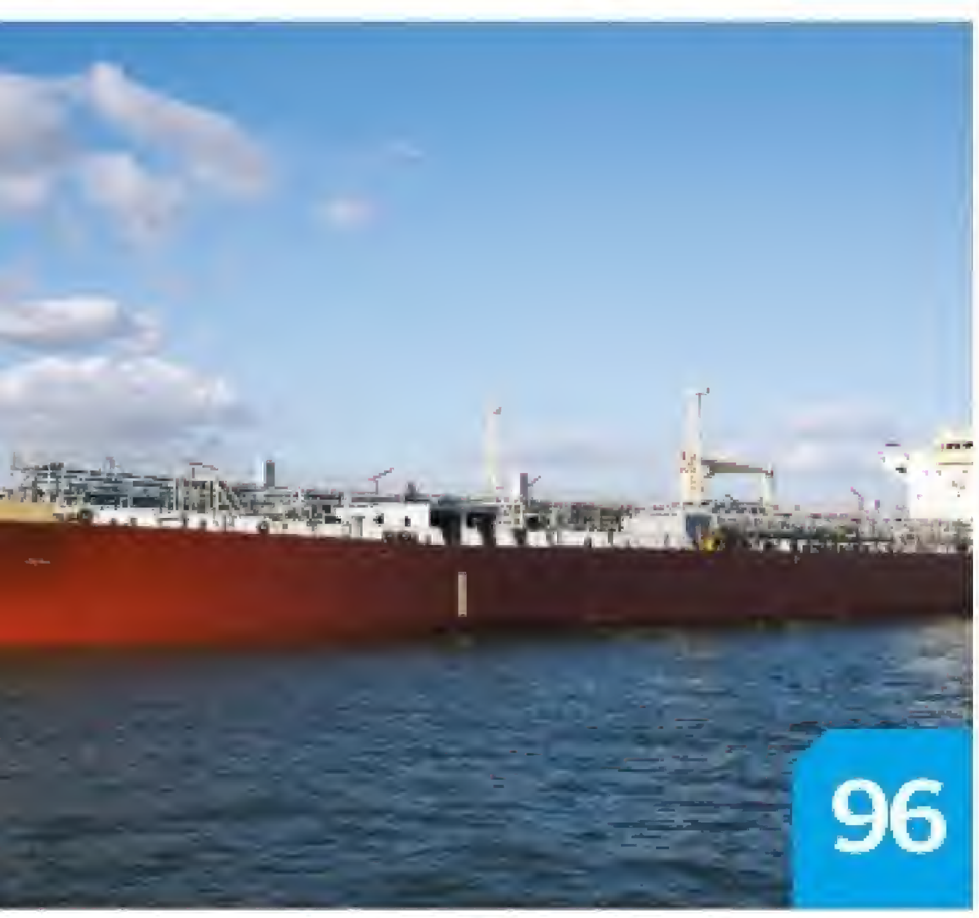
SEA

Set sail aboard these remarkable marvels


84

102


100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92

THE NEW AGE OF SAIL

Meet the fleet of new wave ships that are giving sail power a 21st century makeover

Once upon a time, sail ships dominated the seas. Yacht-like clippers raced to be the first to bring back tea, spices and even gold from Asia to 19th century Europe. Perhaps the most famous was the Cutty Sark, which broke records when it sailed from London to Sydney in little over 70 days, reaching speeds of over 17 knots (31.5 kilometres per hour) in the process.

Trailing behind the clippers were the mighty windjammers, which carried up to 5,000 tons of heavy cargo, such as lumber, between continents. Even with five large masts and broad square sails they averaged approximately 7.5 knots (13.9 kilometres per hour).

Both clippers and windjammers were reliant on following the prevailing winds to circumnavigate the world. The opening of the Suez Canal in 1869 signalled the end of the age of sail. It offered a shorter route from the North Atlantic to the Indian Ocean, but travelled inland where winds were weakest. Steam ships became the preferred option, then the more efficient diesel engine.

Shipping continues to be the main way we transport goods today. In fact, shipping has grown by 400 per cent since the 1970s, and there are now an estimated 100,000 ships at sea carrying the products we consume. In our globalised world, 90 per cent of our international trade is now transported via the sea. But the 16 largest cargo ships can produce as much sulphur pollution as 800 million cars.

This is in part due to container ships burning low-grade 'bunker fuel', which is even more harmful than the refined petrol we use in cars. Regulations exist to control shipping emissions, but the harmful particles are believed to be responsible for thousands of human deaths each year. Organisations like the Sustainable Shipping Initiative are working to reform the industry by 2040, but climate change is moving faster.

However, a new generation of sailors and ship builders may have an environmentally friendly solution, which will draw on the past in order to save the future. The last decade has seen traditional sailing ships refitted to transport small quantities from the tropics like the clippers of old.

Meanwhile, the rising cost of fuel is also forcing big businesses that transport vast quantities to innovate, such as experimenting with modern twists on the classic windjammer. And the eco-friendly innovations of wind power aren't limited to cargo transport, with even luxury yachts like the Maltese Falcon utilising sails.

"The 16 largest cargo ships can produce as much pollution as 800 million cars"

The iconic Cutty Sark clipper transported cargo around the world between 1870 and 1922

Reinventing the sail rig

When the Maltese Falcon hoisted its sails on the yachting scene in 2006 it was hailed as revolutionary. Its sails were aerodynamically curved and the masts turned by hydraulics towards the best angle for the wind. Though it looked cutting-edge, the technology was actually developed by a German engineer in the 1970s.

Wilhelm Prölss, who worked for Shell Oil for 30 years, proposed an entire cargo ship built with freestanding, rotating sails, which he called the Dynaship (also known as DynaRig), as a way to get around surging fuel prices during the 1973 oil crisis. However, his ideas were not properly tested until American billionaire Tom Perkins commissioned the Maltese Falcon. This was in part because the technology wasn't there in the 1970s; hydraulics were not reliable enough and the masts were too heavy. But recent advances, especially in carbon fibre, have changed that.

Since its maiden voyage in 2006, the Maltese Falcon has proven the DynaRig concept works. Dykstra Naval Architects, which helped design the Maltese Falcon, have developed plans for the Ecoliner cargo ship in line with Prölss' original vision.

The Maltese Falcon super-yacht is proof that the concept for other eco-friendly ships, like the Ecoliner cargo vessel, can work

©Getty; Thinkstock

RADICAL REDESIGN

This container ship acts as a giant airfoil so it can sail directly into the wind

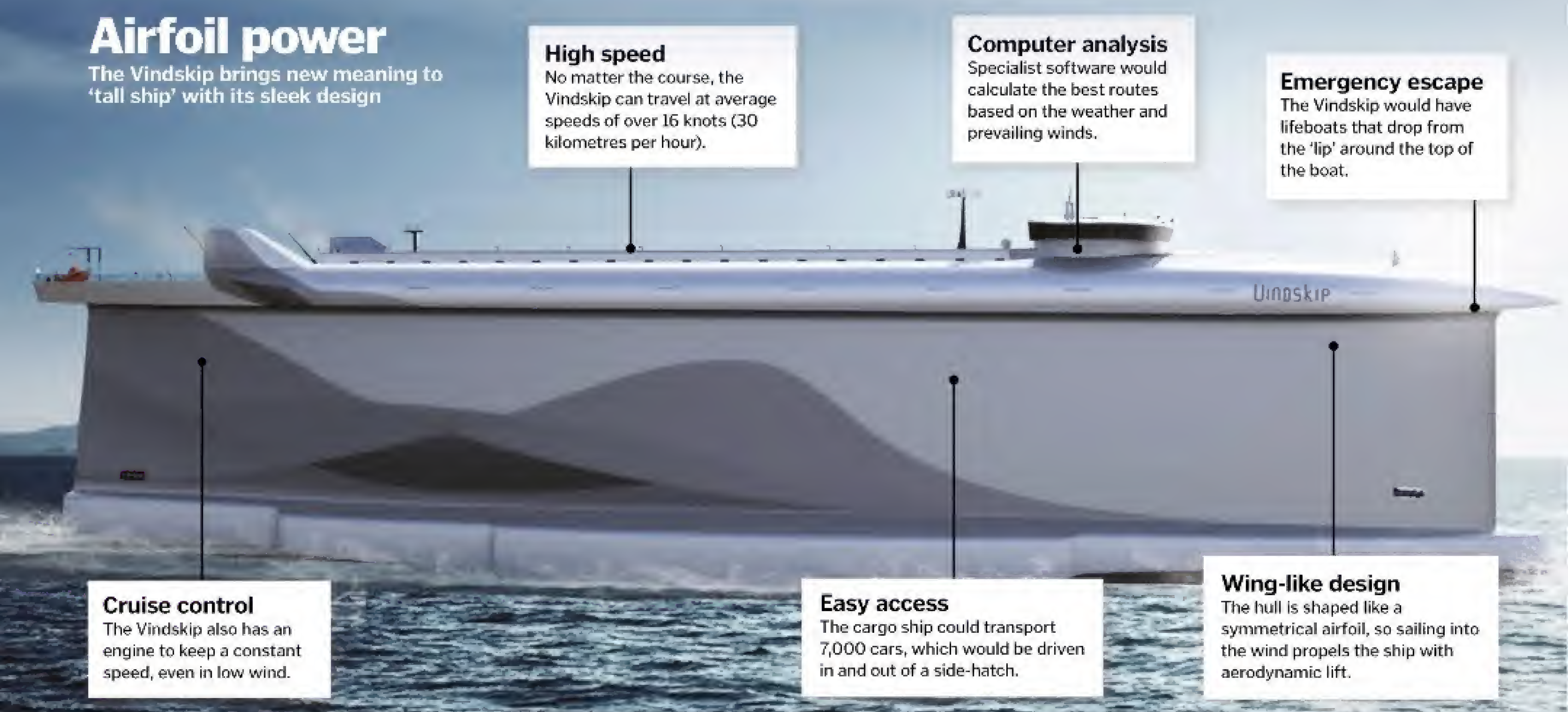
While the Ecoliner offers a modern twist on the classic sail ship, the Vindskip takes its lead from airplane designs. The ship has a uniquely shaped hull, with high sides that curve outwards like the shape of a plane's wing. This means that rather than sailing with the wind, the Vindskip would sail into the oncoming wind. Its airfoil shape would harness a force akin to aerodynamic lift, pulling the ship forwards.

Like the Ecoliner, the Vindskip is also a hybrid, equipped with a liquefied natural gas engine to get it going from a standstill. But because wind power will help to drive the Vindskip out at sea, the engines can be small, meaning that more space is free to store cargo, all the while achieving fuel savings of 60 per cent and reducing emissions by an impressive 80 per cent.

This innovative vessel was designed by Norwegian firm Lade AS, and there are plans for the first Vindskip merchant ships to appear by 2019 provided ship builders license the design.

Airfoil power

The Vindskip brings new meaning to 'tall ship' with its sleek design



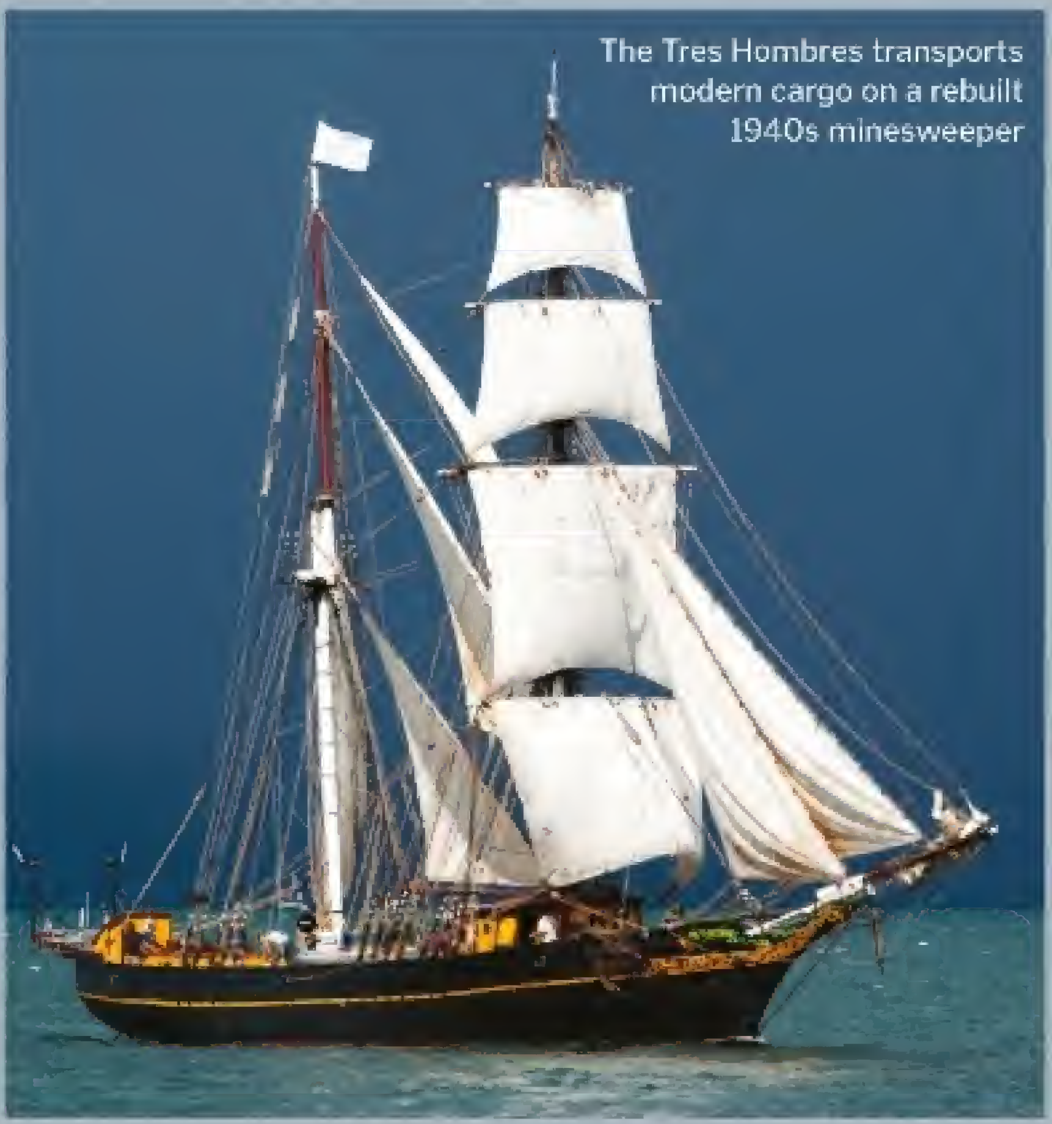
TRADITIONAL TRANSPORT

Romantic rum-runners leading the eco-revolution

The Tres Hombres schooner looks like a relic from the first age of sail. But it has actually only been sailing since December 2009, and is at the forefront of the return to wind power. It's owned and operated by Fairtransport, a Dutch organisation dedicated to making eco-friendly cargo shipments a reality.

Rather than being fitted out with any cutting-edge technology, the Tres Hombres relies on a traditional complement of 12 sails. Despite this, it's kick-starting the wind power revolution by transporting rum, coffee and cocoa across the Atlantic with 90 per cent less carbon emissions. With only 35 cubic metres of space available for cargo, the Tres Hombres is not going to provide for all of the world's shipping needs. But it is not alone.

Fairtransport's Sail Cargo Alliance is currently developing a number of other ships, and another company, Sail Cargo Inc, just successfully crowdfunded their own carbon-neutral clipper, powered by a mix of wind and solar power. The drive towards greener shipping has truly begun.


The Tres Hombres transports modern cargo on a rebuilt 1940s minesweeper

A HIGH-FLYING FIX

Automated sails can reduce the amount of fuel existing ships use

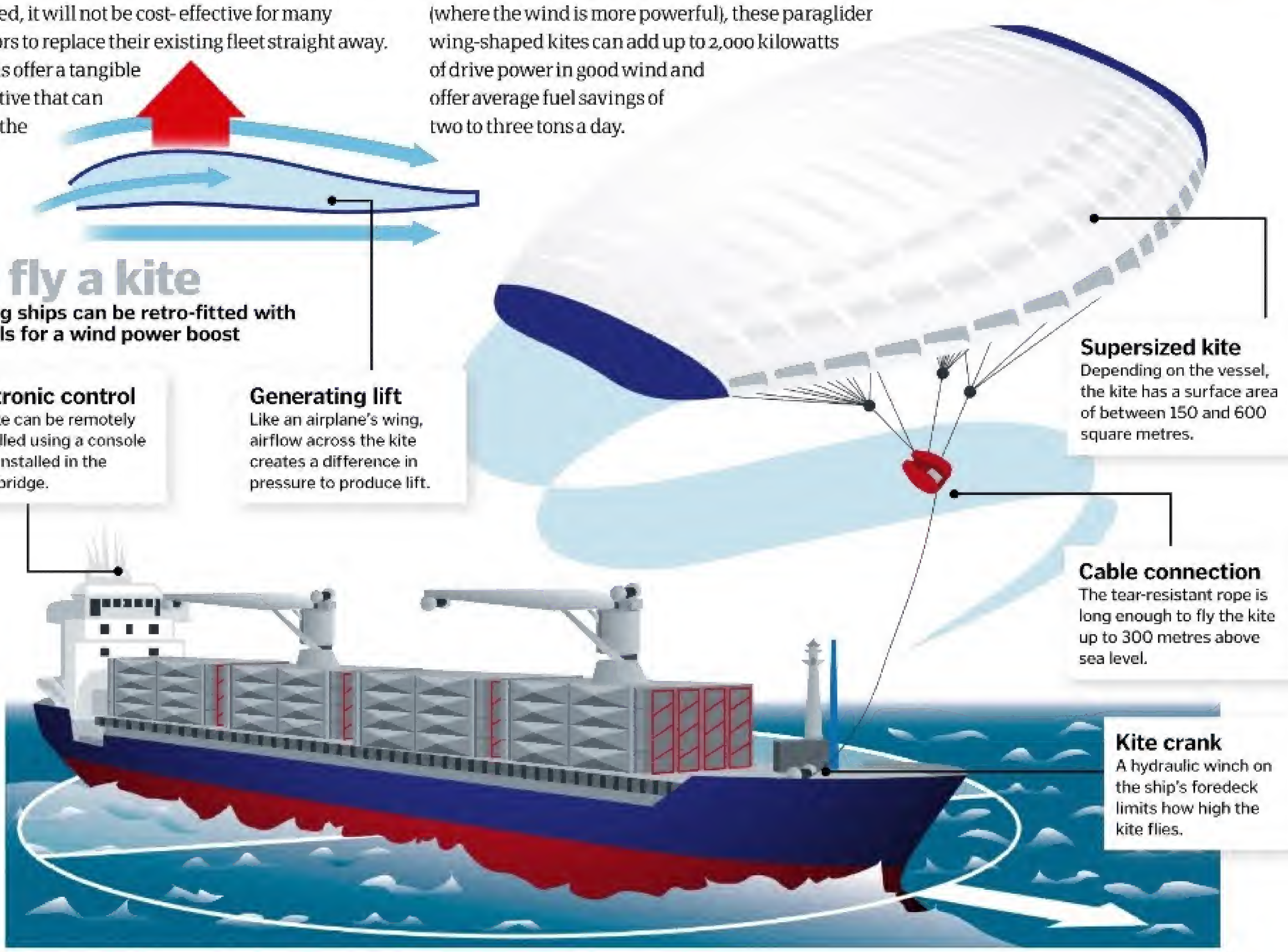
While there are lots of ideas for new wind-assisted ships, most are only at the prototype stage and are several years from setting sail. Meanwhile, 50,000 cargo ships will continue to pollute and contribute to climate change.

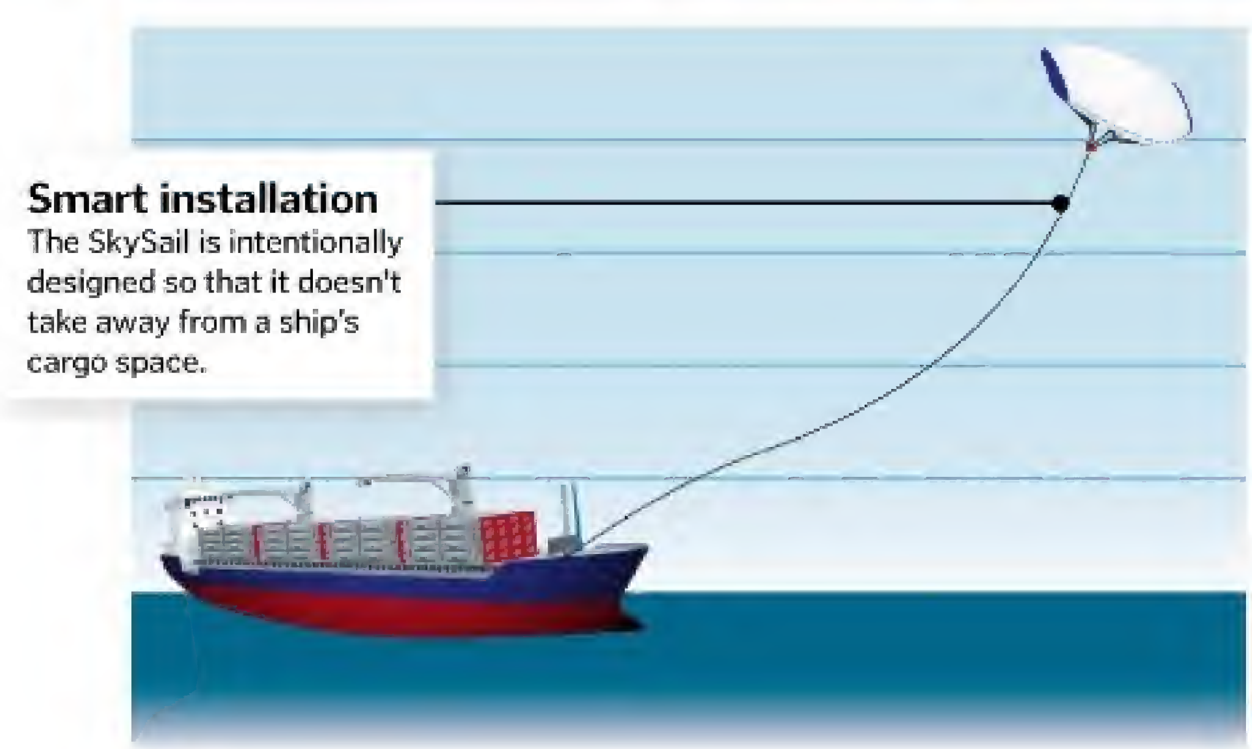
Even once the Ecoliners and Vindskip concepts are perfected, it will not be cost- effective for many operators to replace their existing fleet straight away. SkySails offer a tangible alternative that can reduce the amount of fuel today's merchant ships use immediately by retro-fitting them with tech to harness wind power.

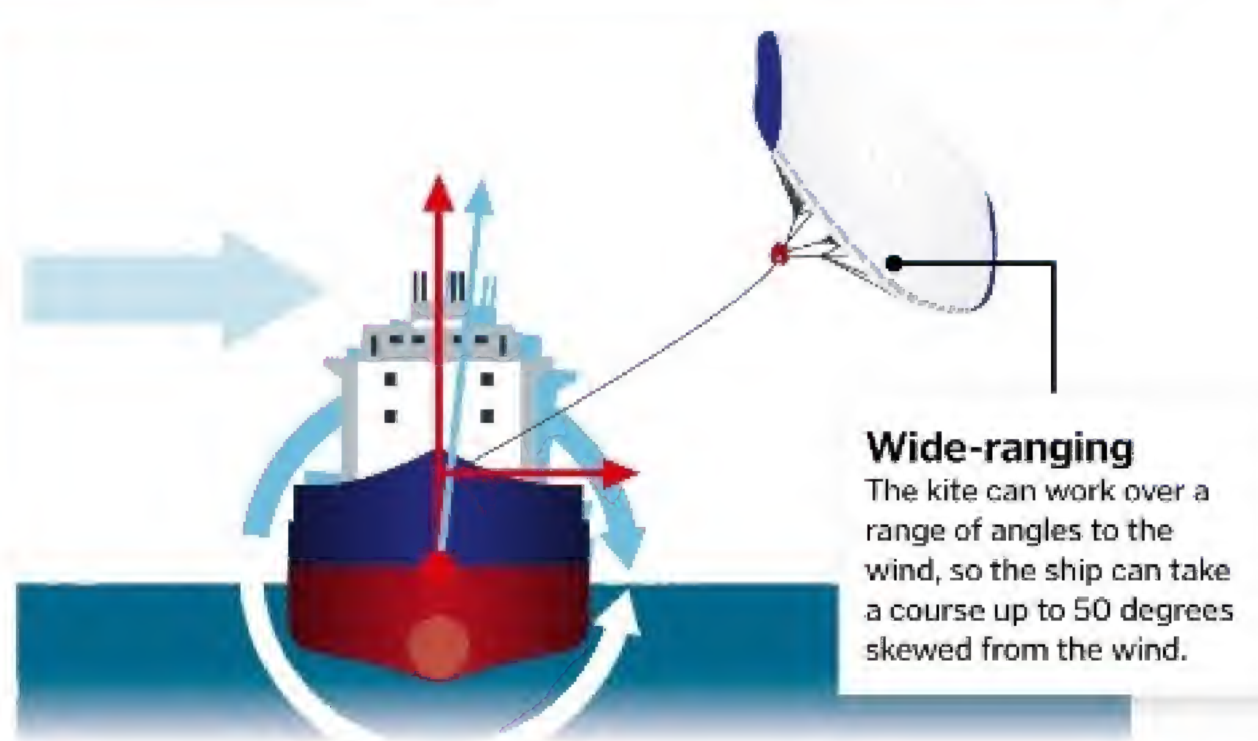
Based in Germany, so far the company has equipped five ships with the kites. While they are not as powerful as sails, when flown at high altitude (where the wind is more powerful), these paraglider wing-shaped kites can add up to 2,000 kilowatts of drive power in good wind and offer average fuel savings of two to three tons a day.

Go fly a kite

Existing ships can be retro-fitted with SkySails for a wind power boost







Ocean hunters

These amazing feats of engineering bring the ocean depths closer than ever before

What lies beneath? This question has fascinated mankind for decades. We know more about the surface of the Moon than we do about our planet's deep oceans, as the limitations of planning a visit to the bottom of the sea are as many as venturing into space. But when nature throws problems at us, we hit back with technological solutions.

It's thought an English innkeeper, musing over the properties of buoyancy and water displacement, dreamt up the first submarine in 1580. From there, the principal of taking humans from sea level down to the deepest-known parts of the ocean in a pressurised cabin has grown into a colossal industry, important to scientists, the military and explorers alike.

But what are the benefits of diving so deep and what is there to see? Studying the seabed and its geological and topographical properties at certain regions can help us learn more about the surface of our planet. Scientists studying plate tectonics can learn plenty from ocean trenches, gaining knowledge that may lead to some great advancements in earthquake predictions and tsunami warning systems.

Similarly, the study of the decaying matter that collects on the ocean floor may help us to understand more about how carbon cycles through our ecosystems and how it is stored in the oceans. In turn this may have implications for our understanding of climate change.

Submersibles are manned submarines, usually carrying around three crew members. One of the most famous and longest-serving submersibles out there is Alvin, the first of its kind capable of carrying passengers, owned by the Woods Hole Oceanographic Institution in Massachusetts, USA. Also available for deep-ocean exploration and study are ROVs, or Remotely Operated Vehicles. These are robots that can be controlled from their parent ship, equipped with cameras and tools to take images and samples from the deep.

At the bottom of the ocean, hydrostatic pressure is a major adversary. For every ten metres (33 feet) in depth, the pressure increases by one bar (14.5 pounds per square inch). At full-ocean-depth, that

Emerging technology is behind many of Virgin Oceanic's new deep-sea exploration vessel

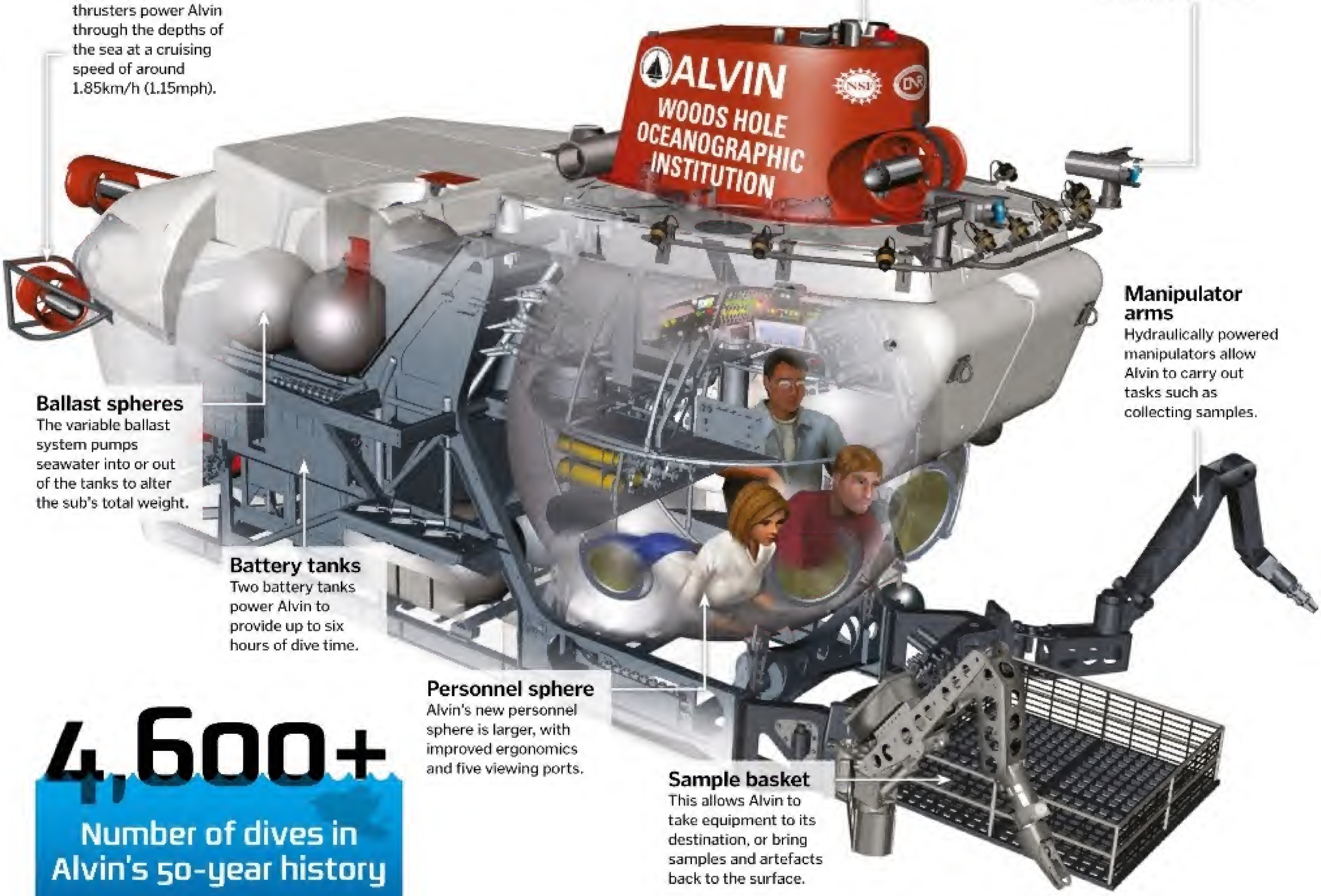
Virgin Oceanic submersible

Explore Richard Branson's innovative craft for deep-ocean adventure, designed by sub builder Graham Hawkes

11,034m
The depth this sub is expected to achieve
Pressure hull
The pilot lies on their stomach inside a cylindrical tube made of 13cm (5.1in)-thick carbon fibre.
Submarine wings
Like an aircraft in reverse, these hydrodynamic 'wings' are designed to pull the sub downward.
Virgin
Buoyant foam
The sub's buoyancy is provided by syntactic foam, made up of tiny microspheres of hollow glass set in epoxy.
oceanic
oceanic
Thrusters
Working in harmony with the wings, these thrusters allow the sub to cruise up to 10km (6.2mi) over the ocean floor.
Viewing dome
Breaking with submersible tradition, this semicircular dome is made of synthetic quartz and offers a panoramic view of the deep.

Inside Alvin

Take a tour of one of the longest-serving deep-sea submersibles in ocean science



Thrusters
Seven reversible thrusters power Alvin through the depths of the sea at a cruising speed of around 1.85km/h (1.15mph).

Sail
Known as the sail, this holds the hatch where the pilot and passengers enter the submersible before the pressure hull.

Cameras and lights
High-definition cameras are present on Alvin to record dives, as well as LED lights to light the way.

Manipulator arms
Hydraulically powered manipulators allow Alvin to carry out tasks such as collecting samples.

Ballast spheres
The variable ballast system pumps seawater into or out of the tanks to alter the sub's total weight.

Battery tanks
Two battery tanks power Alvin to provide up to six hours of dive time.

Personnel sphere
Alvin's new personnel sphere is larger, with improved ergonomics and five viewing ports.

Sample basket
This allows Alvin to take equipment to its destination, or bring samples and artefacts back to the surface.

4,600+

Number of dives in Alvin's 50-year history

means the pressure equals the weight of an elephant balancing on a postage stamp. To survive that, deep-sea craft need to be extremely tough.

The outer shells of subs and ROVs need to be made of a substance that won't buckle under the astonishing pressure. Titanium is often used, because it's incredibly strong, corrosion resistant and is also able to withstand both the freezing depths of marine trenches and the soaring temperatures of hydrothermal activity.

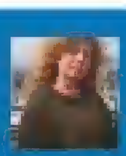
The pressure hull of a submersible is the area that needs to be hardiest of all, keeping the internal pressure comfortable for human occupation. A sphere is the most common form, as with this specific shape the pressure is applied equally. Many submersibles feature spherical personnel pods constructed of one element, with no joins that may weaken the structure. DOER Marine's Deepsearch submersible employs this technique, with their sphere made out of incredibly tough glass.

One submersible that uses a radically different pressure hull is Virgin Oceanic's sub. This features a cylindrical compartment made of 13-centimetre (5.1-inch) -thick carbon fibre, capped with a see-through viewing dome constructed of incredibly strong synthetic quartz.

Another key element of submersible design is buoyancy. The craft needs to descend, ascend and be able to 'hover' in the water column at the pilot's direction. Many submersibles, both manned and remotely-operated, use water bladders to provide ballast. These can be filled or dumped at will to ensure that the craft can manoeuvre within the water column.

To make submersibles and ROVs float, many possess ceramic spheres filled with air, packed in to their body. The spheres are often fitted alongside syntactic foam, a light substance made of glass microspheres mixed in epoxy resin. These features work alongside the ballast and also function as a safety feature. If the submersible encounters problems at depth, any expendable weight can be dropped and the buoyancy will lift the sub to the surface.

Remotely Operated Vehicles (ROVs) come in many different configurations, with a large range of depth capabilities and uses. Many are used by



Ask an oceanographer

Liz Taylor, president of DOER Marine reveals the challenges of deep-sea exploration

What are the main issues faced by deep-sea exploration today?
We have the capacity and technology to build both manned and unmanned systems that can reliably reach the deepest parts of the ocean. What is lacking is the willingness to effectively fund exploration; for meaningful exploration to occur, we must be willing to accept that not all expeditions will go as predicted. Sometimes, the greatest discoveries are made by accident.

What technology has DOER Marine developed?
We have worked to develop applied science, multi-mission ROVs and submersibles for a broad array of tasks. Our systems are designed to evolve with new technology and client needs. For example, the 6000m [19,685ft] ROV delivered to the University of Hawaii last year supports a variety of disciplines, from backing up the manned submersibles program, to servicing the Station Aloha Ocean Observing System, documenting historic wrecks and old munitions sites as well as carrying out basic geological and biological survey and sampling tasks. It is equipped with HD cameras, supports multiple sensors and has Gigabit Ethernet maximising the data collecting capacity.

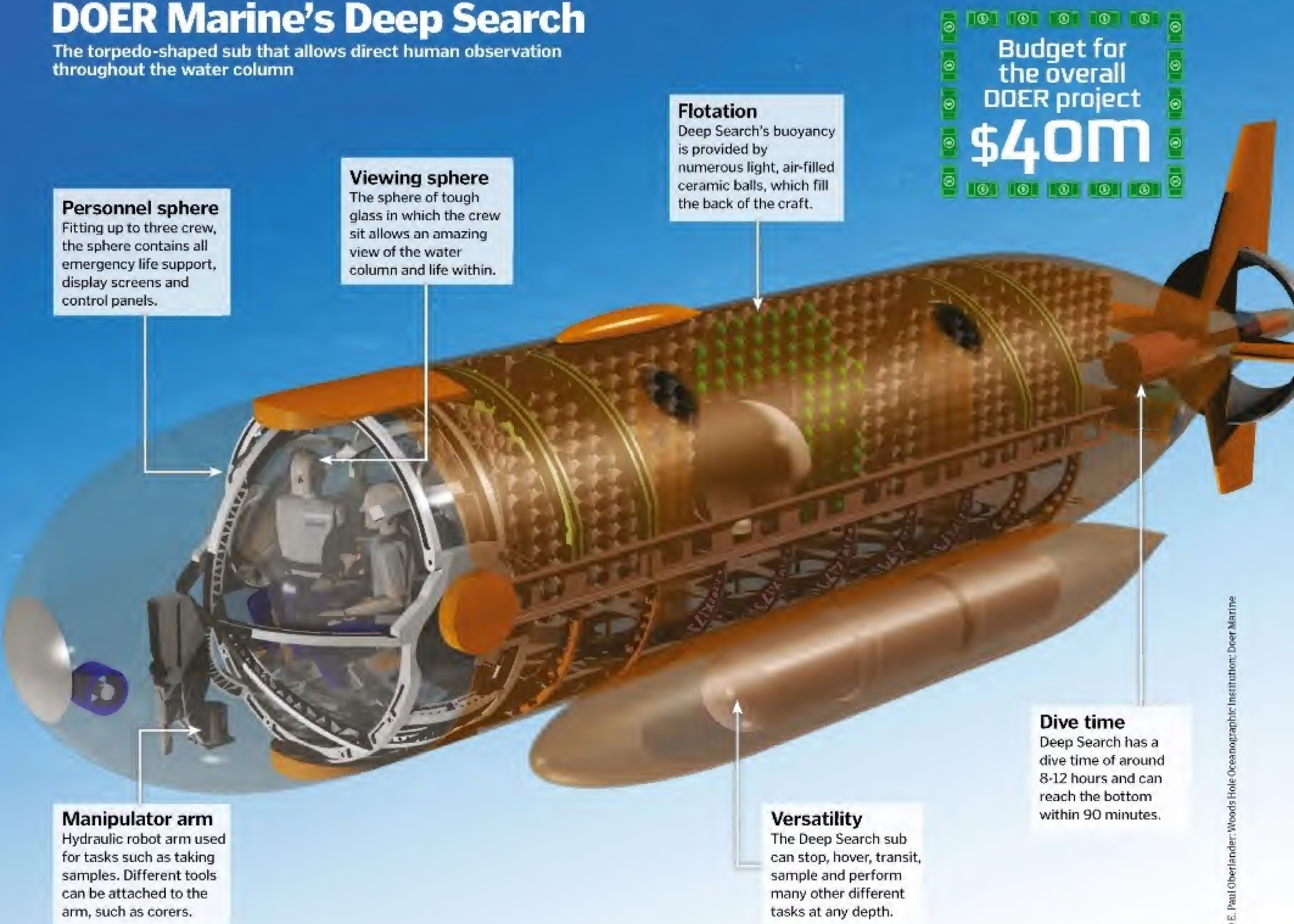
What are the main advancements in the field in the last few years?
The major advances have been in materials science, processing power and reduced size of many components. However, for the human-occupied submersibles, battery technology advances have been a game changer.

What are the major discoveries that new deep-sea technology has helped to unearth?
Some of the most interesting discoveries that have been made have to do with promising new medicines from the sea. Scripps Institute of Oceanography scientists have been working with microbes found to be effective in combating flesh-eating bacteria. The Canadian Cancer Society has funded research involving deep-water sponges. Sponges are also being studied and modelled in artificial kidney research. The biggest discovery, really, is how much more there is still to know about the ocean.

What does the future hold for deep-sea exploration?
There has been much talk about moving toward the exclusive use of robots and sensors [in deep-sea exploration]. However, sensors and drones are great tools to have but they don't possess intuition and they can't act on a hunch. They can't be surprised nor can they return to directly share stories, igniting the imagination and compelling others to care. Knowing what we do now know about the ocean, and its importance to our survival, I think we will continue to "go down to the sea in ships" (and in submersibles) but perhaps more as stewards rather than as despoilers.

DOER Marine's Deep Search

The torpedo-shaped sub that allows direct human observation throughout the water column



the oil industry for drilling support or sub-sea construction, the navy for search and recovery missions and by scientists to explore the ocean and collect data.

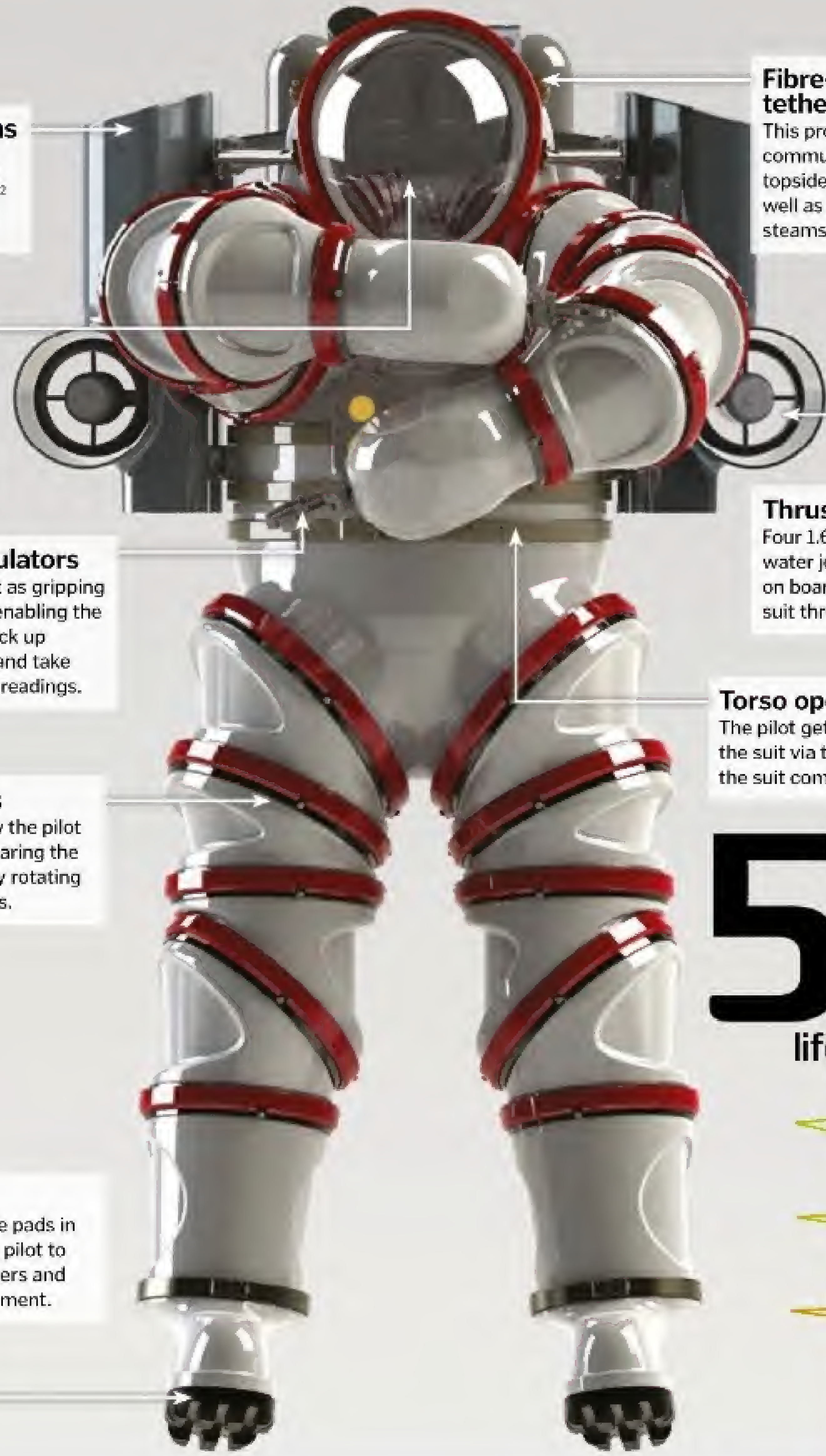
All ROVs have a camera that links a video feed to their parent boat. From here, the operator is then able to guide the vehicle through a task. The robot will often have various highly specialised functions, for example, hydraulically powered manipulator arms that are fully wieldable by the person at the robot's controls. ROVs can be used to accomplish tasks that regular humans simply couldn't do, to be used in the ocean the same way scientists would use rovers and landers in space. Some ROVs operate using a fibre-optic umbilical tether. This connects the robot to the boat and passes information between the control centre and the undersea unit. Using a tether can limit the ROV's depth capabilities, but it also provides a level of security in that the ROV is less easily lost at sea. That is, until the tether becomes tangled or snagged. Other ROV systems are able to operate tether-free, either breaking away from their cable at depth, for example Woods Hole Oceanographic Institution's (WHOI) 'ABE', which stands for Autonomous Benthic Explorer.

The advantage of using a Remotely Operated Vehicle (ROV) to explore the deep ocean, recover shipwrecks or collect samples is that it poses no risk to human life. Removing the human element from the equation also means ROVs are cheaper to build and use.

However, many oceanographers argue that the work of a robot underwater is no comparison to the reactions of a human brain. Life support in submersibles is a huge part of their makeup. The pilot and passengers need to be kept at a constant pressure, comfortable temperature and supplied with breathable air. The CO_2 and water vapour exhaled by the crew needs to be removed (this is often achieved using the same method as used on a space ship) and contingency scenarios need to be in place for every conceivable emergency. In James Cameron's Deep Sea Challenger expedition, his pilot sphere was engineered to condense water

Personal deep sea exploration

As mere humans, superpowers are beyond our reach but sometimes technology lets us mimic these powers pretty well. If you've ever dreamt of breathing underwater or exploring the ocean depths without a submersible, then take a look at the Iron Man-esque ExoSuit. With regular SCUBA gear, divers are limited by the effects that pressure has on the human body and by lengthy decompression stops. However this 'wearable' submersible is a suit that can take the pilot from sea level all the way down to a dizzying 305m (1,000ft) in relative comfort, with up to 50 hours of life support. Made of aluminium alloy and weighing in at 250kg (550lb), the astronaut-style suit also has four thrusters to propel it. The suit, working alongside an ROV equipped with cameras and video equipment, will enable marine scientists to get first-hand experience of the life they study beneath the waves.



Oxygen systems
With up to 50 hours available, the suit's O_2 stores allow for multiple dives.

Viewing port
The port is teardrop-shaped, allowing a wide field of view down the chest level for the pilot.

Manipulators
These act as gripping devices, enabling the pilot to pick up samples and take scientific readings.

Rotary joints
These joints allow the pilot to move while wearing the suit. They work by rotating at different angles.

Foot pads
Pressure-sensitive pads in the feet allow the pilot to control the thrusters and direction of movement.

Fibre-optic tether
This provides two-way communications with topside scientists as well as live video steams from the suit.

Thrusters
Four 1.6-horsepower water jet thrusters are on board to propel the suit through the water.

Torso opening
The pilot gets in and out of the suit via the torso, where the suit comes apart.

50 hours of life support

A prototype of the innovative ExoSuit in preliminary testing

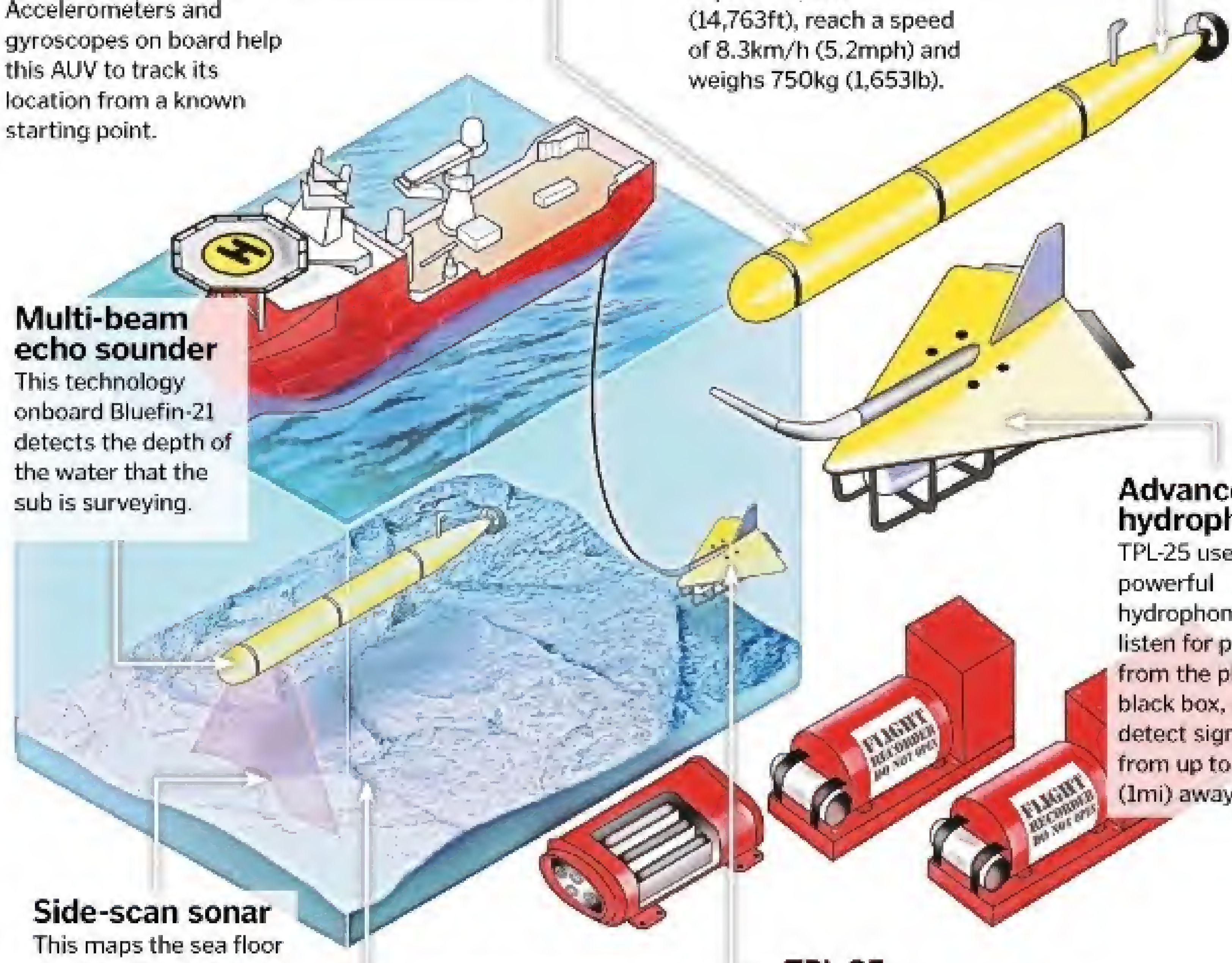
Search and rescue subs

One of the great uses for submersibles and remotely operated vehicles is their ability to go where humans can't, and for long periods of time. This is why they are incredibly useful as search and rescue devices. In the past, the 1966 Woods Hole Oceanographic Institution's DSV (Deep Submergence Vehicle) Alvin was tasked with locating a missing hydrogen bomb, lost in a plane crash in the Mediterranean Sea. Alvin searched for two months before recovering the bomb, complete with attached parachute, under 762m (2,500ft) of water.

A more recent example of submersible search and rescue is the use of autonomous underwater vehicle (AUV) Bluefin-21 in the search for missing plane MH370. On 8 March 2014 a Malaysia Airlines flight from Kuala Lumpur to Beijing disappeared from radar and was presumed to have crashed into the southern Indian Ocean. With such a huge search area to cover in order to find the missing plane, Bluefin-21 was drafted in to help the effort.

The AUV is equipped with side-scan sonar – acoustic technology that creates pictures of the seabed using reflected sound waves instead of light. Bluefin-21 can be programmed to search a particular area, sweeping and scanning 50m (164ft) above the seabed for 24 hours, after which the data can be downloaded and analysed. This creates a 3D map of the area and highlights any wreckage that could potentially be linked to the missing plane.

Unfortunately, despite having scanned over 850km² (328mi²) of the vast search area, at the time of writing Bluefin-21 has yet to locate the missing aircraft.



Navigation system
Accelerometers and gyroscopes on board help this AUV to track its location from a known starting point.

Vital stats
Bluefin 21 can dive to a depth of 4,500m (14,763ft), reach a speed of 8.3km/h (5.2mph) and weighs 750kg (1,653lb).

Multi-beam echo sounder
This technology onboard Bluefin-21 detects the depth of the water that the sub is surveying.

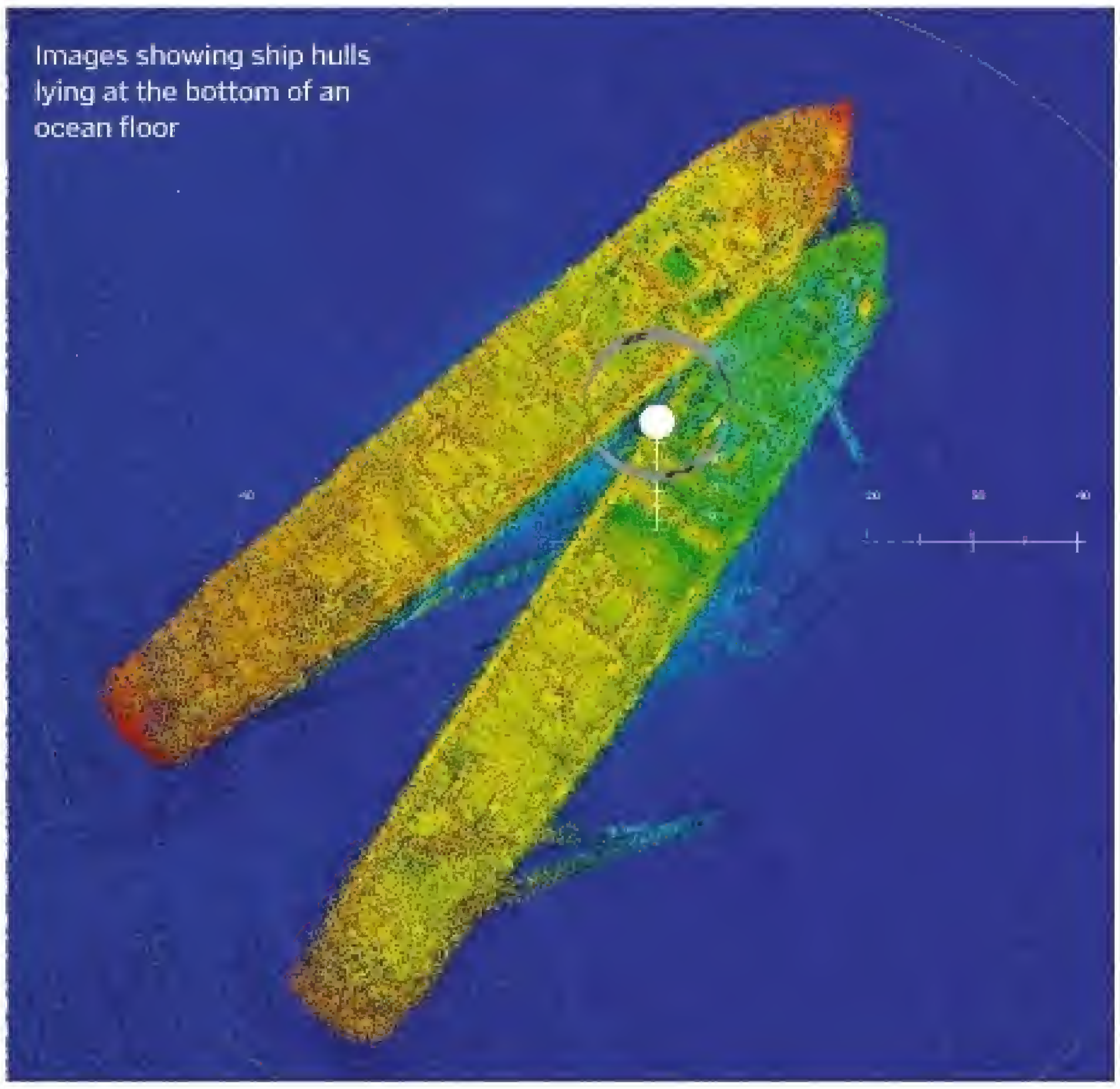
Advanced hydrophone
TPL-25 uses a powerful hydrophone to listen for pings from the plane's black box, able to detect signals from up to 1.6km (1mi) away.

Side-scan sonar
This maps the sea floor to show if any fuselage has come to rest on the ocean floor.

Distance searched
The TPL-25 system can search an area of over 260km² (100mi²) per day.

TPL-25
Also used in the search for MH370 was the Towed Pinger Locator 25, towed behind a research vessel.

The design of Bluefin-21 is reminiscent of a torpedo



Images showing ship hulls lying at the bottom of an ocean floor

vapour and sweat from the pilot into a special bag, which could be drunk in an emergency.

Other types of undersea robots are capable of guiding themselves, after being programmed, to carry out a task. These are known as AUVs, or autonomous underwater vehicles. This kind of mini submarine is used for scanning larger areas of the ocean, as AUVs are able to work for much longer than a manned sub and dive much deeper than an ROV.

One such device is Nereus, owned by WHOI. This is a HROV, (H for Hybrid). The robot can be programmed to venture off alone and scan the sea floor using sonar mapping and camera systems; if it finds anything interesting it can then be returned to the site via a lightweight tether and equipped with extra sampling apparatus at the command of scientists aboard the ship.

A similar method is usually used for other, smaller AUVs such as Bluefin-21, developed by Bluefin Robotics. This AUV is capable of mapping the sea floor using echo sounders and side-scan sonar for up to 24 hours. GPS systems then return it to a parent ship, where the data is then analysed by the scientists.

If anything of interest is found, Bluefin-21 can return to the exact site with high-resolution imaging gear on board to give scientists a closer look. Alongside the external features, submersibles and ROVs require a whole host of other technology on board.

The deepest realms of the ocean are pitch black, so most submersibles and ROVs have powerful lights to provide illumination in the depths. These, as well as everything else on the sub, are battery powered. The battery life of a sub governs exactly how much 'bottom time' is allowed, alongside the ascent and descent rates. Many submersibles still use lead-acid batteries in their power cells, but lithium-ion is now being introduced into many. Stage II of Alvin's latest upgrade is set to see the inclusion of lithium-ion batteries to extensively improve the sub's bottom time.

Typical manned submersibles will have an on-board computer to log data and monitor all electronic systems. As well as GPS and navigational tracking systems, sonar, communications apparatus (Cameron's record-breaking sub could even send text messages), subs and ROVs will also have many different sensors to monitor the parameters outside the craft and send the data back for analysis in real time. Many submersibles and ROVs can also be fitted with all kinds of specialised equipment, depending on the task that it is set to accomplish.

History of deep-sea explorers

Take the plunge into a story of the ever-increasing depths humans have reached

1 Deepsea Challenger
10,908m (35,787ft)

2 Exosuit
305m (1,000ft)

3 Virgin Oceanic
11,034m (36,201ft) (expected)

4 SonSub Innovator
3,000m (9,843ft)

6 Alvin
4,500m (14,764ft)

7 Bluefin-21
4,500m (14,764ft)

8 Shinkai 6500
6,500m (21,325ft)

9 Kaiko 7000II
7,000m (22,966ft)

11 Johnson Sea Link
914m (3,000ft)

12 Seaeye Lynx ROV
1,500m (4,921ft)

13 Deep Worker 3000
1,000m (3,280ft)

14 Magnum Plus
3,962m (13,000ft)

15 Hercules
4,000m (13,123ft)

16 Sentry
6,000m (19,685ft)

17 MIR DSV
6,000m (19,685ft)

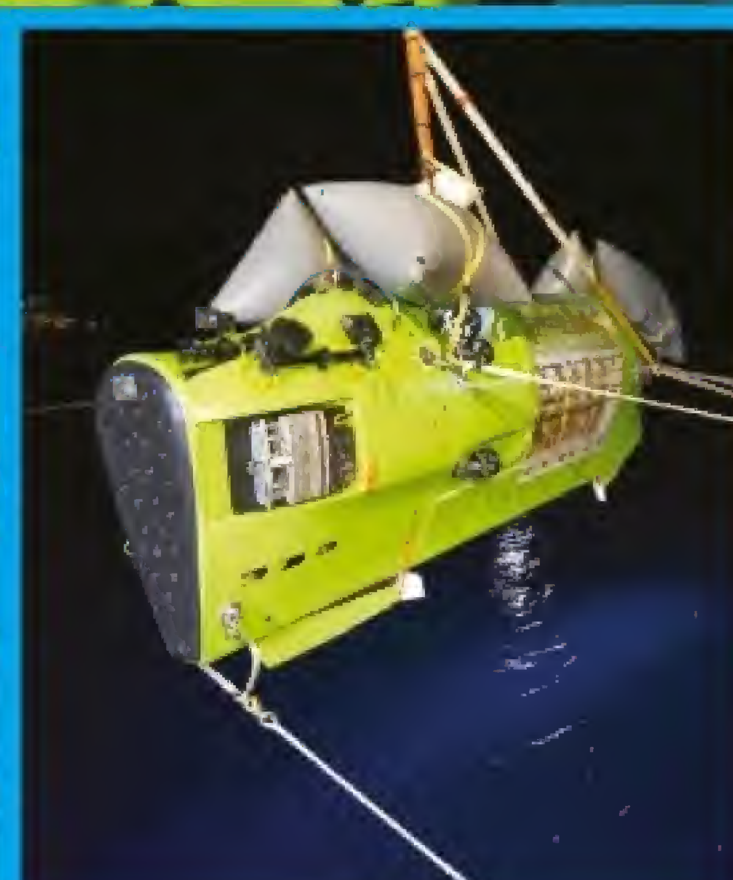
18 Nautile
10,902m (35,768ft)

The Challenger Deep revisited

Fast-forward 54 years, and the abyssal Mariana Trench gets her second batch of human visitors. No one had returned since Piccard and Walsh's adventure, until James Cameron completed his Deep Sea Challenger expedition on 26 March 2012.

Deep Sea Challenger is a submersible like no other. Nicknamed a 'giant runner bean', the sub's architecture veers away from the bulky cuboids of standard sub design and is long, thin and descends vertically into the depths. The sub gradually spins on its ascent and descent to keep it on track. The pilot sits inside a tight, spherical cockpit with custom circuit boards powered by large versions of model aeroplane batteries. The exterior has a huge bank of lights to illuminate the voyage.

Cameron descended to 10,908m (35,787ft) armed with high-definition cameras and video equipment alongside state of the art sampling apparatus. Piccard and Walsh were unable to document their dive, but Cameron has more than made up for that, with his feature-length documentary about Deep Sea Challenger set to hit cinemas in the near future.



5 Deepsearch
5,000m (16,404ft)
(expected)

10 Deep Flight Super Falcon Mark II
120m (394ft)

FAR RIGHT It took engineers seven years to develop the sub

RIGHT James Cameron prepares to descend to the Mariana Trench

© Rex features; Peters & Zabransky

Amphibious machines

Take a look at the cutting-edge vehicles that are able to jump between land, water and air as a result of some innovative engineering

The dream of a fully functional amphibious vehicle dates back to the mid-1700s, when an Italian prince drove a modified land/water coach into the Tyrrhenian Sea. Despite the odd universal desire to drive our cars into the nearest lake, only the Amphicar, a steel beauty with stylish tailfins, achieved anything close to commercial success, selling 4,500 units in the Sixties.

Other 'amphibians' have had greater success – namely amphibious aircraft. That's because a simple amphibious plane or helicopter can be made by adding sturdy floats to a pair of landing skids. But amphibious land/water vehicles face many more obstacles, because the engineering rules of the water are often in direct conflict with the rules of the land. For example, a high-speed watercraft needs to break the plane of the water to reduce drag. Picture the wide, hydrodynamic shape of a speedboat hull, which lifts the nose of the boat up and out of the water. The body of a sports car, on the other hand, needs to be low and flat to reduce drag and safely hug the road during sharp turns. So how do you engineer the body of a vehicle that can navigate both surf and turf with ease and speed?

Modern amphibious vehicles have several key advantages over earlier models. Materials, for example. The Amphicar was pure steel, which not only rusts and corrodes, but makes it heavy as a rock. To keep a steel craft afloat, you

The statistics...

Quadski

Crew: 1
Length: 3.2m (10.5ft)
Width: 1.6m (5.2ft)
Height: 1.4m (4.6ft)
Weight: 535kg (1,180lb)
Max land speed: 72km/h (45mph)
Max water speed: 72km/h (45mph)

need a lot of water displacement, which demands a bulky body that looks odd on the road. Today's amphibious cars and ATVs are built from composite material – a strong and lightweight blend of plastics and fibre. These lighter bodies sit higher in the water and require less speed to break the plane.

Propulsion is another huge obstacle. Earlier motorised amphibious vehicles relied on propellers for thrust. Propeller blades had to be small in order to ride high enough on the road to avoid damage, and small propellers provide less thrust. Modern amphibians have switched to water jet propulsion systems with no moving parts outside the craft. Water jets take in water through a hole in the bottom of the hull and use power from the engine to turn a centrifugal pump to build up pressure. The pressurised water is then forced through a nozzle in the rear, providing forward thrust.

The military has always been a great supporter of amphibious vehicles, with landing craft, troop movers and jeeps playing critical strategic roles since World War II. With continued military funding and engineering breakthroughs, we might see a commercially viable amphibious car sooner than you think.

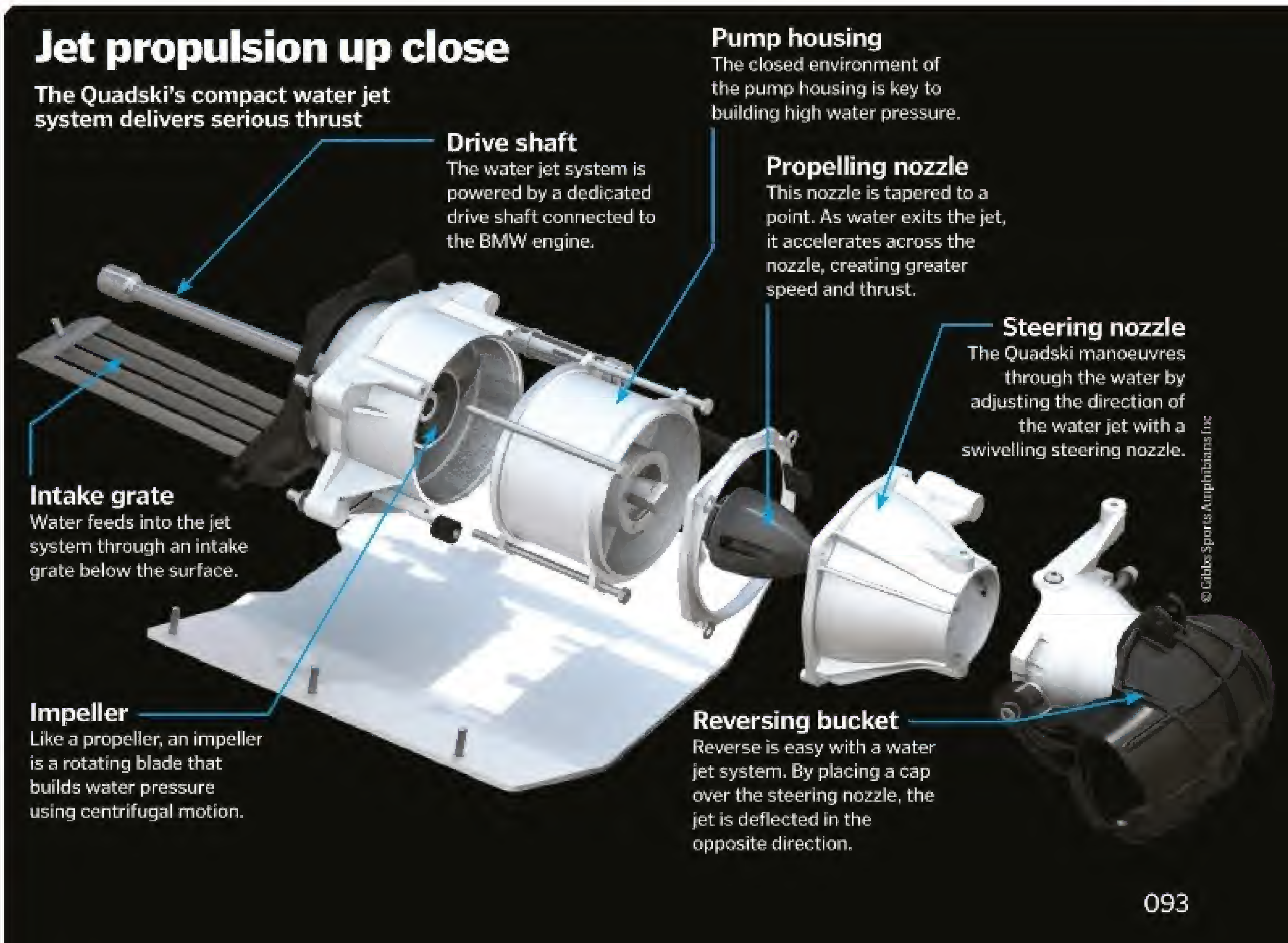
Gibbs Sports Quadski

A quadbike that goes from turf to surf in just five seconds

The Quadski is an amphibious transformer, switching from ATV to jet-ski at the push of a button. The quick-change act centres on the wheels, which fully retract in five seconds thanks to two zippy servomotors. On land, the Quadski looks and rides exactly like a quadbike. For mud-chewing trail rides, the Quadski is powered by the same 130-kilowatt (175-horsepower), 1.3-litre motorcycle engine that supercharges BMW's high-performance racing line. For safety reasons, the engine is capped at 60 kilowatts (80 horsepower) on land, reaching a maximum 72 kilometres (45 miles) per hour. But the real magic is seeing this lightweight ATV move from land to water. Previous amphibian car concepts were literally dead in the water, slogging slow and low. The Quadski, however, leaps out of the water using the full 130 kilowatts (175 horsepower) to pump water through its jet propulsion system. By riding high on the surface on its fibreglass hull, the Quadski can match its maximum land speed on the water.

Jet propulsion up close

The Quadski's compact water jet system delivers serious thrust



Rinspeed sQuba

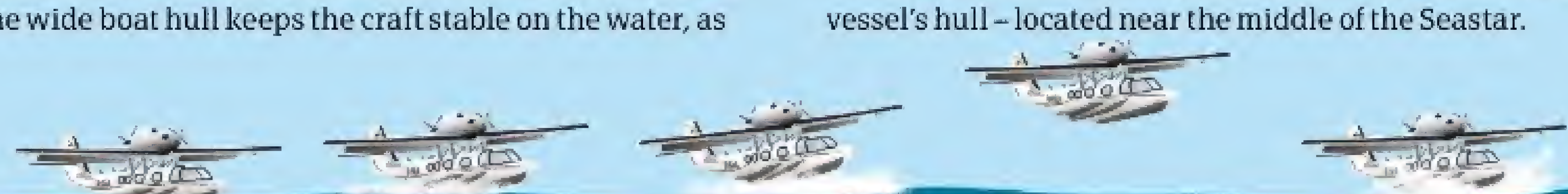
A James Bond fantasy car brought to life

Rinspeed CEO Frank Rinderknecht had dreamt about an underwater 'flying' car since seeing *The Spy Who Loved Me* in 1977. 007's swimming car was the direct inspiration for the sQuba, a modified Lotus Elise with three battery-powered electric motors and oxygen masks. When the aluminium-bodied, watertight Lotus drives into a lake, it floats. With the flick of a switch, power is diverted to two propellers and two water jets to reach a leisurely surface cruising speed of 5.9 kilometres (3.7 miles) per hour. Getting the sQuba to dive requires driver and passenger to open doors and windows to flood the cabin. To travel at the maximum depth of ten metres (33 feet), the driver must use the water jets. On land, the zero-emissions sQuba can rocket from 0-80 kilometres (0-50 miles) per hour in 5.1 seconds, but maxes out at just 2.9 kilometres (1.8 miles) per hour when underwater.

Dornier Seastar

Land, sea and air: this flying boat's got it all covered

A conventional seaplane is nothing more than a Cessna outfitted with floats. Exposed to seawater, metal seaplanes corrode quickly and require constant maintenance. And without landing gear, they're as waterbound as a tuna. The hull of the speedboat-looking Dornier Seastar, meanwhile, is made entirely of corrosion-proof composite material. For terrestrial destinations, landing gear lowers from the hull. The wide boat hull keeps the craft stable on the water, as does the in-line arrangement of the twin turboprop engines positioned directly over the cabin. The push-pull action of the two propellers can see the Seastar take off – with up to 12 passengers – after just 760 metres (2,500 feet) and reach a maximum air speed of 180 knots (333 kilometres/207 miles per hour). Short takeoffs and landings are aided by two sets of curved sponsons – side projections that add stability to a vessel's hull – located near the middle of the Seastar.



Boat mode
The Seastar is a boat that flies – rather than a plane that floats – so it sits low and steady in the water on its V-shaped hull.

Breaking the plane
Two sets of sponsons make the hull wider under the wings. The sponsons act almost as hydrofoils to raise the hull when moving.

Liftoff
With the nose of the hull out of the water, drag is greatly reduced, so the Seastar can reach takeoff speed in 760m (2,500ft).

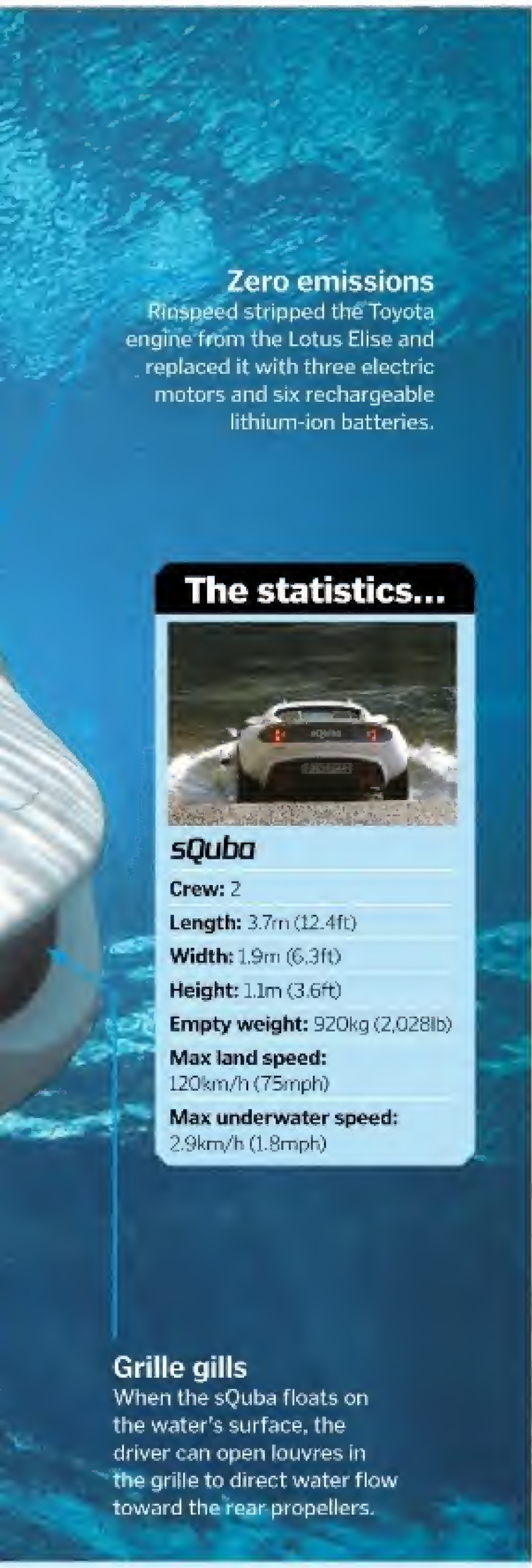
Gaining altitude
The push-pull configuration of the twin turboprop engine results in huge thrust so the Seastar can climb 396m (1,300ft) per minute.

Water landing
The sponsons double up as 'water wings'. As the Seastar touches down, the sponsons create just enough drag to slow it.

The statistics...

Seastar

Crew: 2
Wingspan: 17.6m (58ft)
Length: 12.5m (41ft)
Height: 4.8m (15.9ft)
Empty weight: 3,289kg (7,250lb)
Max speed: 333km/h (207mph)
Max altitude: 4,572m (15,000ft)



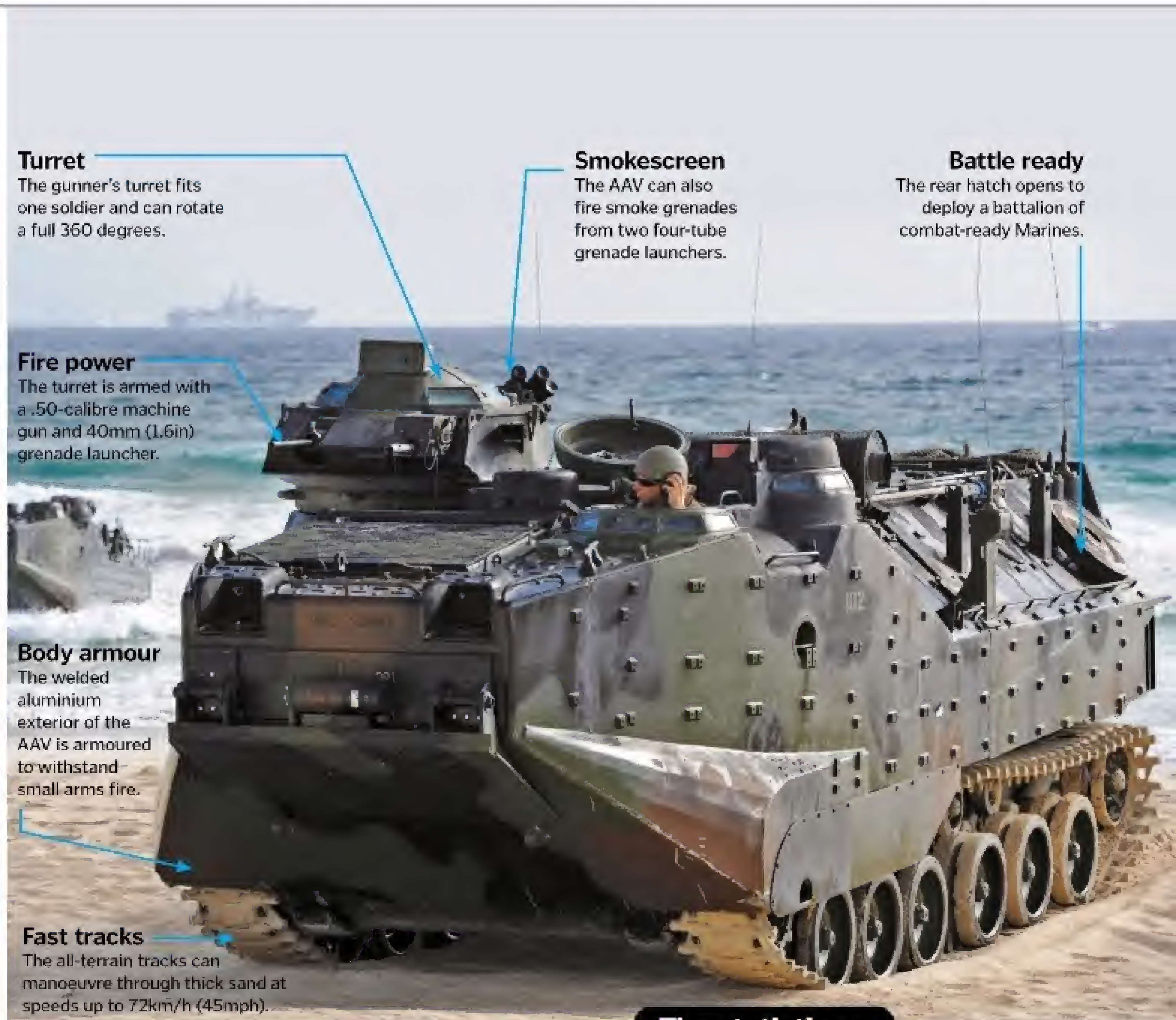
Zero emissions
Rinspeed stripped the Toyota engine from the Lotus Elise and replaced it with three electric motors and six rechargeable lithium-ion batteries.

Grille gills
When the sQuba floats on the water's surface, the driver can open louvres in the grille to direct water flow toward the rear propellers.

The statistics...

sQuba

Crew: 2
Length: 3.7m (12.4ft)
Width: 1.9m (6.3ft)
Height: 1.1m (3.6ft)
Empty weight: 920kg (2,028lb)
Max land speed: 120km/h (75mph)
Max underwater speed: 2.9km/h (1.8mph)



Turret
The gunner's turret fits one soldier and can rotate a full 360 degrees.

Smokescreen
The AAV can also fire smoke grenades from two four-tube grenade launchers.

Battle ready
The rear hatch opens to deploy a battalion of combat-ready Marines.

Fire power
The turret is armed with a .50-calibre machine gun and 40mm (1.6in) grenade launcher.

Body armour
The welded aluminium exterior of the AAV is armoured to withstand small arms fire.

Fast tracks
The all-terrain tracks can manoeuvre through thick sand at speeds up to 72km/h (45mph).

Amphibious Assault Vehicle

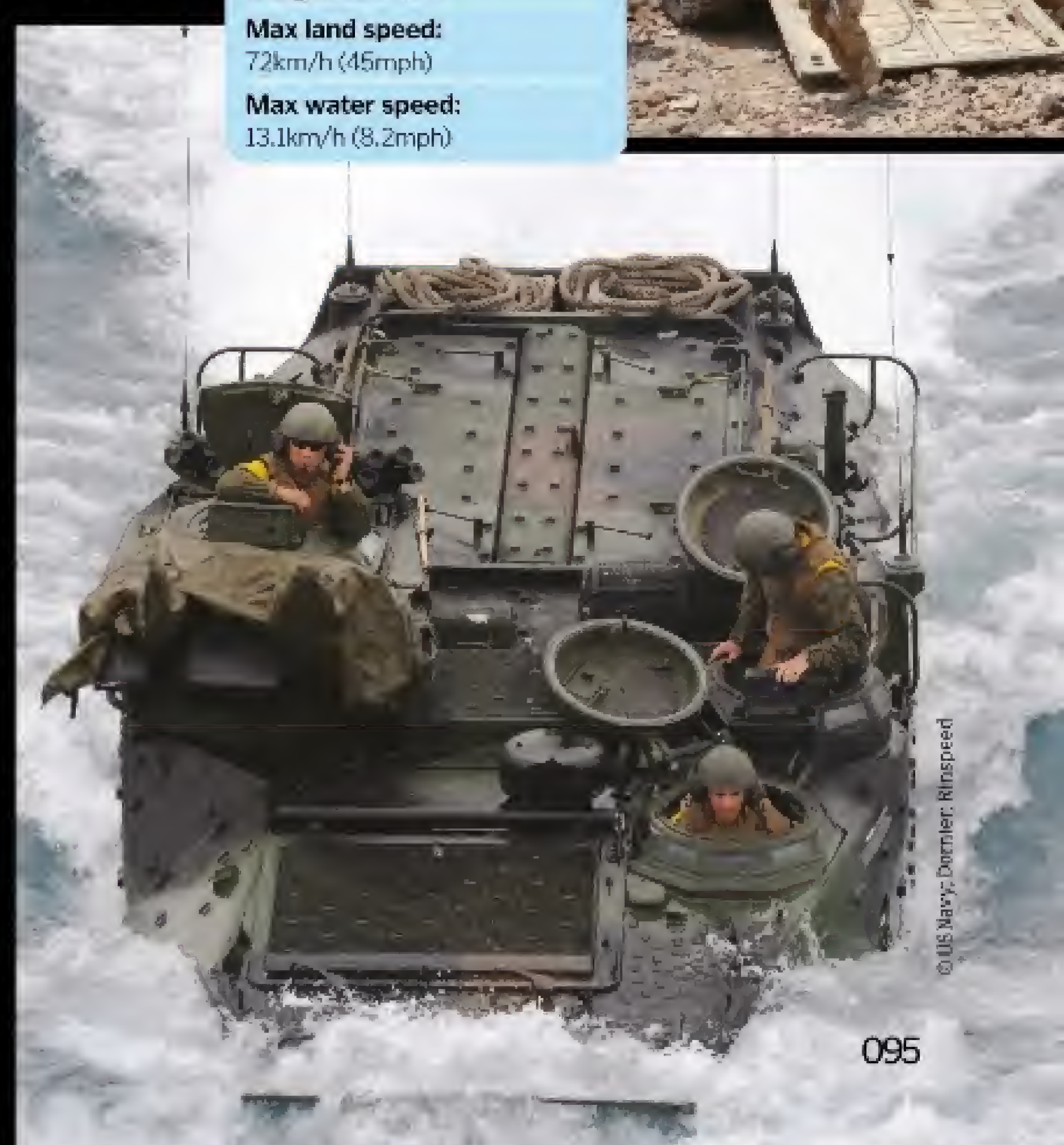
The first to land and the first to fight

Owned by the US Marine Corps, the Amphibious Assault Vehicle (AAV) is a ship-to-shore troop transporter and fully armed combat vehicle. The AAV weighs close to 30 tons and can carry 21 combat-ready Marines and a crew of three. The amphibious tanks launch from the sea-level well decks of assault ships and roar through the water at ten knots (18.5 kilometres/11.5 miles per hour) powered by two rear water jets. The jets are mixed-flow, reversible pumps that propel 52,990 litres (14,000 gallons) of water per minute. In addition to the jets, the AAV gets some propulsion from its spinning tracks. The AAV rides low in the water and can fire its .50-calibre machine gun and 40-millimetre (1.6-inch) grenade launcher on both land or sea. It makes a seamless transition from ocean to shore and carries enough fuel to haul 4,535 kilograms (10,000 pounds) of cargo as far as 480 kilometres (300 miles) inland.

The statistics...

Amphibious Assault Vehicle

Crew: 3
Length: 7.9m (26ft)
Width: 3.3m (10.8ft)
Height: 3.3m (10.8ft)
Weight: 29.1 tons
Max land speed: 72km/h (45mph)
Max water speed: 13.1km/h (8.2mph)



Supertankers explained

These floating oil fields carry the energy needs of a nation in their ample bellies

The world thirsts for oil. Every day our cars, trucks, furnaces and planes drink up 85 million barrels of crude oil in the form of gasoline, diesel fuel, kerosene, jet fuel and dozens of useful petroleum by-products including that Vaseline you rubbed on your lips this morning. Try to imagine what 85 million steel drums of oil look like – and that's one single day. While Europe and North America remain the largest consumers of oil, our addiction to energy is now a global phenomenon. There is only one way to transport millions of barrels of black gold from the rich oil fields of Russia and Saudi Arabia to the US, Japan and beyond: within the bellies of the largest ships in the world.

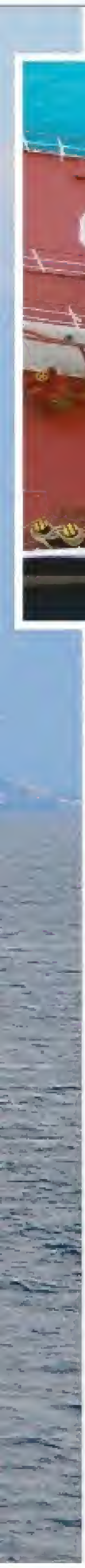
Supertankers are high-seas oil tankers that have been supersized to satisfy our colossal modern energy appetite. The biggest of these floating behemoths can carry the equivalent of over 3 million barrels of crude oil in its dozens of below-deck storage tanks; that amounts to more oil than England and Spain consume every day.

Over the course of a year, hundreds of supertankers criss-cross the world's oceans and arctic seas transporting over 2 billion barrels of oil with tremendous efficiency. Second only to oil pipelines, these massive ships cost the equivalent of two US cents per gallon to operate.

That's not to say they're cheap. A brand-new ultra large crude carrier (ULCC) will cost £80-100 million. They are constructed in the goliath shipyards of South Korea and China, which combine to handle over 80 per cent of the world's shipbuilding. Supertankers are welded together from huge prefab structures called megablocks. The vessels are designed with two chief goals in mind: to maximise the amount of oil the ship can carry; and get it to its destination safely.

The first way to maximise carrying capacity is to get bigger. The largest supertanker ever to sail the oceans was the Seawise Giant, weighing in at 564,763 deadweight tons (DWT). If you stood the Seawise Giant on its stern, it would be taller than nearly every skyscraper in the world. Today's supertankers hover around the more reasonable, but still gigantic, 300,000 DWT mark.

In addition to sheer size, supertankers maximise their carrying capacity by filling nearly the entire hold with storage tanks. Modern tankers don't carry actual barrels. Oil is pumped from the shore through a system of on-deck pipelines into dozens of below-deck storage tanks. By using many smaller



A bird's-eye view of the prow of an oil tanker

storage tanks, shipbuilders minimise the effects of sloshing (see 'Slosh dynamics' box). While a smaller tank filled to capacity won't slosh and shift its weight on the high seas, a large, half-empty tank could slosh with enough force to capsize even a supertanker. Once the ship reaches its destination, a powerful on-board pump sucks the oil from the tanks and transports it to an on-shore pipeline, storage facility or to a smaller tanker.

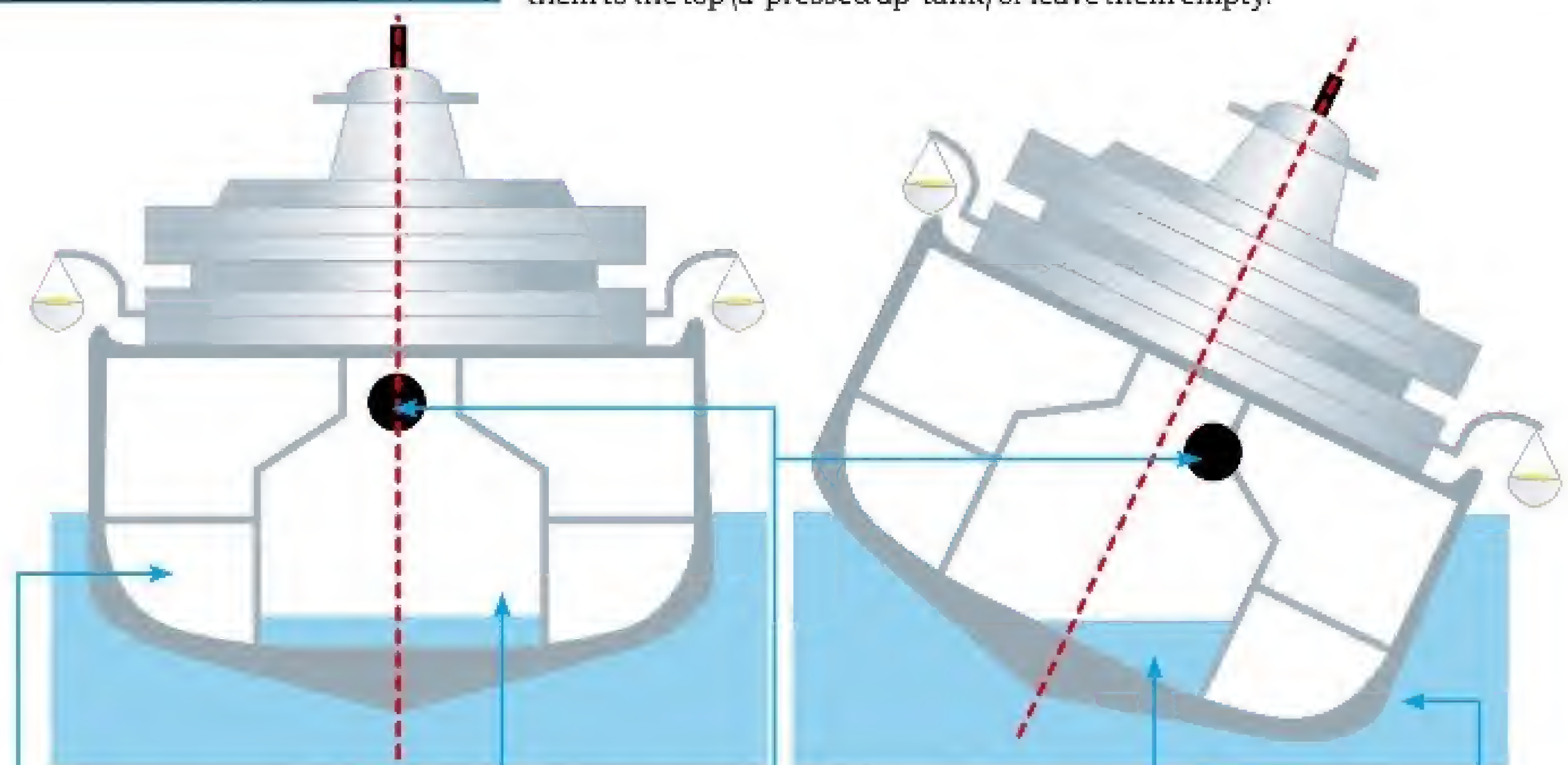
Safety is a major consideration on a supertanker. First and foremost, you are transporting massive quantities of a highly flammable liquid. (Every oil tanker features a large stencilled 'No smoking' sign over the crew quarters!) It turns out that the greatest danger is not the oil itself, but the vapours that can become trapped in the partially filled tanks. That's why modern oil tankers employ an automated inert gas system that fills unused portions of a storage tank with a cocktail of gases that render the vapour inflammable.

Oil leaks and spills are another big concern, both for economic and environmental reasons. In the wake of the infamous Exxon Valdez oil spill in 1989, all modern oil tankers are required to have double-hull construction. The inner hull containing the storage tanks is protected by an outer hull; these are divided by a three-metre (ten-foot) gap. When the tanker is full, the space between the hulls is left empty, forming an effective crumple zone. When the tanker unburdens its load of oil, the space is filled with water to act as ballast.

Temperature is another serious concern for supertankers. Crude oil and other fuel products can get thick and sticky if they are allowed to become too cold, making them nearly impossible to unload. When supertankers cross through near-frozen arctic waters, they maintain the desired oil temperature by pumping hot steam through coils underneath each storage tank.

Slosh dynamics

Despite their incredible size and weight, supertankers are surprisingly vulnerable to capsizing. That's because they are filled with liquid cargo, which sloshes about with great force, dangerously altering the ship's centre of gravity. The worst scenario is a large storage tank only partially filled. The liquid in this 'slack tank' will slosh and shift with sudden manoeuvres of the ship or outside forces like strong waves or wind gusts. Since the liquid sloshes in the same direction as the roll, it exaggerates the pitch of the vessel, creating something called the free surface effect. As the vessel tries to right itself to centre, the liquid sloshes even more violently in the opposite direction, initiating a positive feedback loop that can eventually lead to disaster. To mitigate the dangers of the free surface effect, supertankers use several smaller storage tanks and either fill them to the top (a 'pressed up' tank) or leave them empty.



Rocking the boat
The free surface effect can be mitigated by using smaller, off-centre tanks and filling them to capacity.

Slack tank
The free surface effect is exaggerated in a partially filled tank, where liquid moves freely over a large area.

Centre of gravity
If enough liquid sloshes with enough force, it can alter the vessel's centre of gravity and leave the ship unable to right itself.

Slosh
If the ship's manoeuvring or an outside force tips it starboard, the liquid will slosh in the same direction, deepening the roll.

Displacement
Normally, a slight roll is counteracted by the upward pressure of the water displaced. Sloshing liquid acts against that correcting force.

Crude oil is a mixture of compounds known as hydrocarbons

What is crude oil?

Crude oil is the raw, unprocessed petroleum that is pumped out of the ground through oil drilling. The composition of crude oil varies greatly with the location of the underground oil deposit. The main ingredient of crude oil is carbon, which makes up 83-87 per cent of the mix. There are also natural gases bubbling through the thick liquid such as methane, butane, ethane and propane, composed of hydrogen, nitrogen, oxygen and sulphur in varying quantities. The black/brown crude is shipped to oil refineries, where it is purified and separated into commodities like gasoline, diesel fuel, kerosene and liquid natural gas.

Deadweight tonnage

Following the principle of Archimedes' "Eureka!" moment, if you lower a floating vessel into water, a force called buoyancy pushes upwards on the hull with a force equal to the weight of the water it displaces. Buoyancy only works on objects that are less dense than water. It is the huge volume of air in the hull that allows supertankers to float. Because displacement equals weight, we can figure out the total weight of a ship – known as deadweight tonnage – by measuring the height of the waterline against markers painted on the ship's hull.

Anatomy of a supertanker

We take an exploded diagram of one of these mighty vessels and detail the key parts

Vents
Flammable vapours can build up in the cargo tanks and must be expelled through on-deck venting systems. The vents ensure that vapours aren't released into confined spaces.

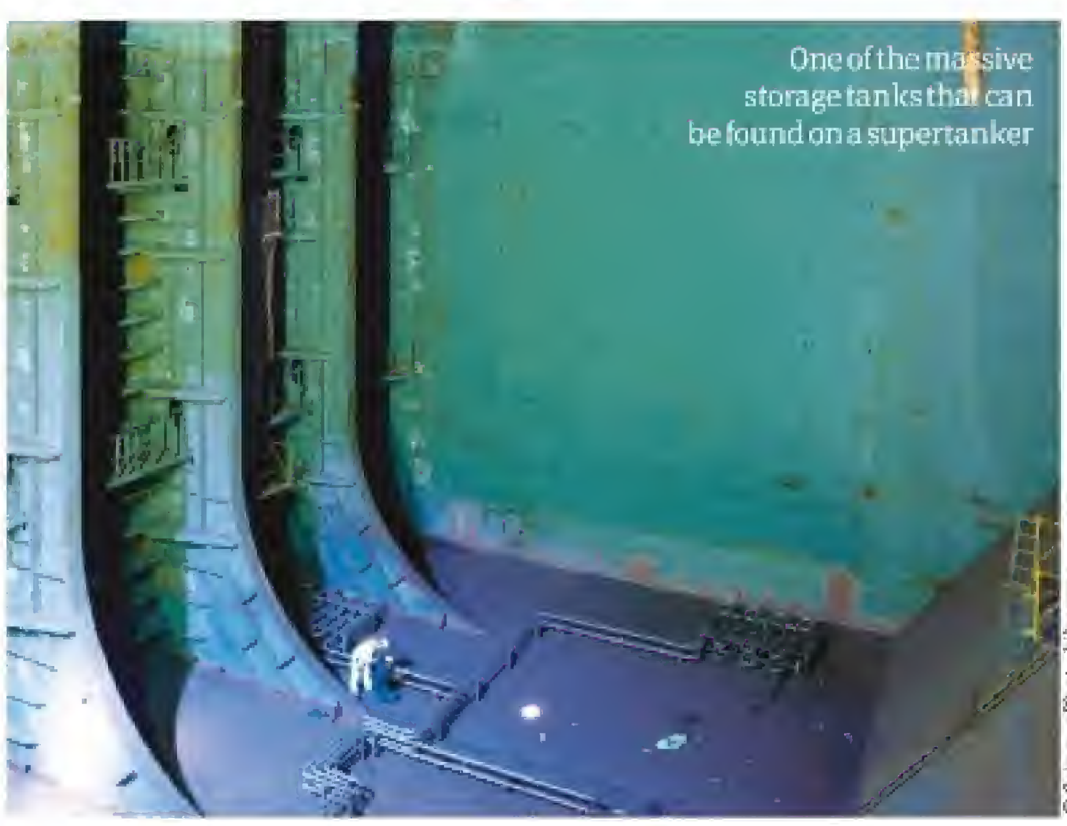
Deck pipelines
These fixed lengths of pipe running along the tanker's deck are used to pump crude oil to and from the shore.

Droplines
These vertical runs of pipe transport oil from the deck pipelines down into the deep storage tanks.

Cargo tanks
The immense hold of the supertanker is divided into a dozen or more storage tanks. No tanks are allowed to straddle the ship's centreline, as this could destabilise the vessel.

Double hull
To prevent spills from low-energy collisions or groundings, all modern oil tankers are built with an outer hull and inner hull separated by a 2-3m (6.6-9.8ft) crumple zone.

Baffles
Each large cargo tank is divided by a series of vertical baffles that minimise the dangerous sloshing effect of fluid cargo.



One of the massive storage tanks that can be found on a supertanker

© Science Photo Library

Oil tanker timeline

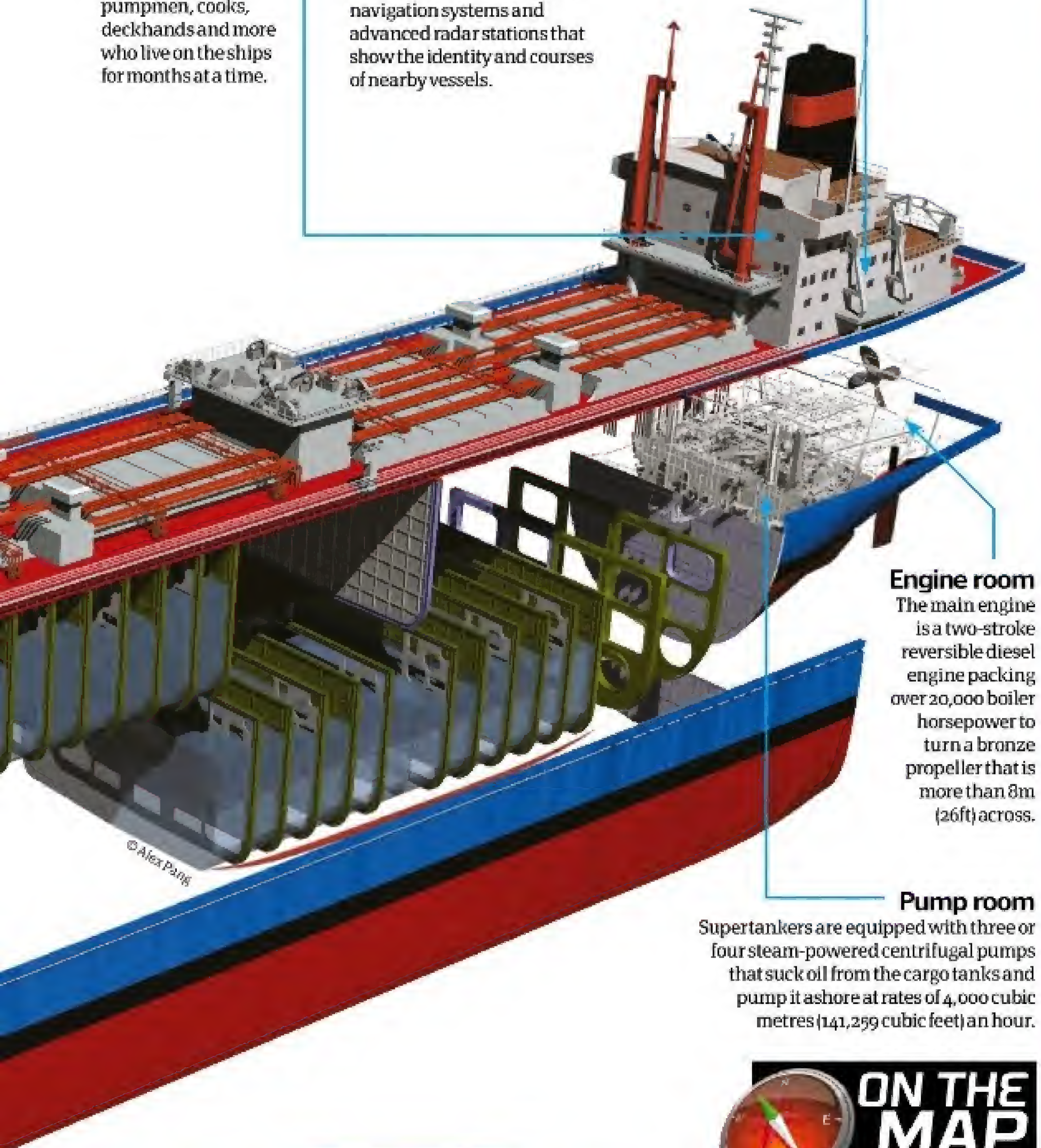
1860s
Wind-powered tankers
A large sailing vessel like the Elizabeth Watts could hold several hundred tons of crude oil, but ocean travel was slow.

1873
First steam tanker
The SS Vaderland is believed to be the first oil tanker powered by a steam engine. They had featured on other types of ship since 1843.

1886
Prototype modern tanker
The British-built Gluckauf was one of the first to have many large, permanent storage tanks in its hold, instead of stacking in barrels.

Crew quarters
Supertankers are manned by skeleton crews of captains, officers, engineers, pumpmen, cooks, deckhands and more who live on the ships for months at a time.

Navigation and communications
Modern supertankers are equipped with satellite communication towers, GPS navigation systems and advanced radar stations that show the identity and courses of nearby vessels.



Engine room
The main engine is a two-stroke reversible diesel engine packing over 20,000 boiler horsepower to turn a bronze propeller that is more than 8m (26ft) across.

Pump room
Supertankers are equipped with three or four steam-powered centrifugal pumps that suck oil from the cargo tanks and pump it ashore at rates of 4,000 cubic metres (141,259 cubic feet) an hour.

ON THE MAP

Top oil producers*

1. **Country:** Russia
   Barrels per day: 9.93m
2. **Country:** Saudi Arabia
   Barrels per day: 9.76m
3. **Country:** United States
   Barrels per day: 9.14m
4. **Country:** Iran
   Barrels per day: 4.17m
5. **Country:** China
   Barrels per day: 4.00m

*Source: US Energy Information Administration

Oil tanker classification

Oil tankers come in all sizes. Here we explain the differences and what it takes to qualify as a supertanker

Medium-range tanker

<44,999 DWT (deadweight tons)

According to a system developed by Shell Oil called the average freight weight assessment, oil tankers are classified by the maximum amount of deadweight tons (DWT) they can carry. Medium-range tankers handle up to 44,999 DWT and include the Seawaymax class of tankers, the largest vessels that can pass from the interior Great Lakes of the US-Canadian border to the Atlantic Ocean via the St Lawrence Seaway.

Long-range tanker 1 (LR1)

45,000-79,000 DWT

Tankers classified as LR1 can carry between 45,000 and 79,000 DWT, which may be small on a supertanker scale, however LR1 tankers do have their advantages. For example, no tanker larger than an LR1 can squeeze through the narrow locks of the Panama Canal, which can shave many miles off a journey.

Long-range tanker 2 (LR2)

<160,000 DWT

Some LR2 tankers are twice as large as the heaviest LR1s, reaching a maximum weight of 160,000 DWT. Smaller tankers in the LR2 class roam the waters of shallower sea basins like the North Sea, Black Sea and the Caribbean. The largest LR2s still float shallow enough to pass through the Suez Canal, thus avoiding the long journey around the southern tip of Africa.

Very large crude carrier (VLCC)

<319,999 DWT

From the VLCC class up is officially supertanker territory. VLCCs weigh in at a maximum 319,999 DWT. VLCCs are also known as Malaccamax craft, because they are the largest tankers that can fit through the Strait of Malacca – a 25-metre (82-foot)-deep pass between Malaysia and Sumatra – the most direct sea route from the oil-rich Middle East to oil-hungry China.

Ultra large crude carrier (ULCC)

<500,000 DWT

These gargantuan vessels – more like small, floating nation-states – are the monsters of the supertanker world, with a maximum carrying capacity of 500,000 DWT. The typical ULCC can transport over 3 million barrels of oil, more than the combined daily energy usage of England and Spain. Most ULCCs are too big to fit through canals, so they must take the scenic route around the southern tips of Africa and South America.

1903

Internal-combustion tankers
Alfred Nobel's brothers, Ludvig and Robert, were oil tanker innovators. The Vandal was their first diesel-electric ship, powered by three 120hp diesel motors.

1915

Wartime refuelling
The USS Maumee was the first large oil tanker used to refuel destroyers on their long Atlantic voyage from America to the UK.

1958

First supertanker
The Japanese-built SS Universe Apollo was the first oil tanker to exceed 100,000 deadweight tons.

XSR48 superboat

The world's first superboat is a £1.2 million masterpiece. As you'd expect, only super-level engineering has been used to create it…

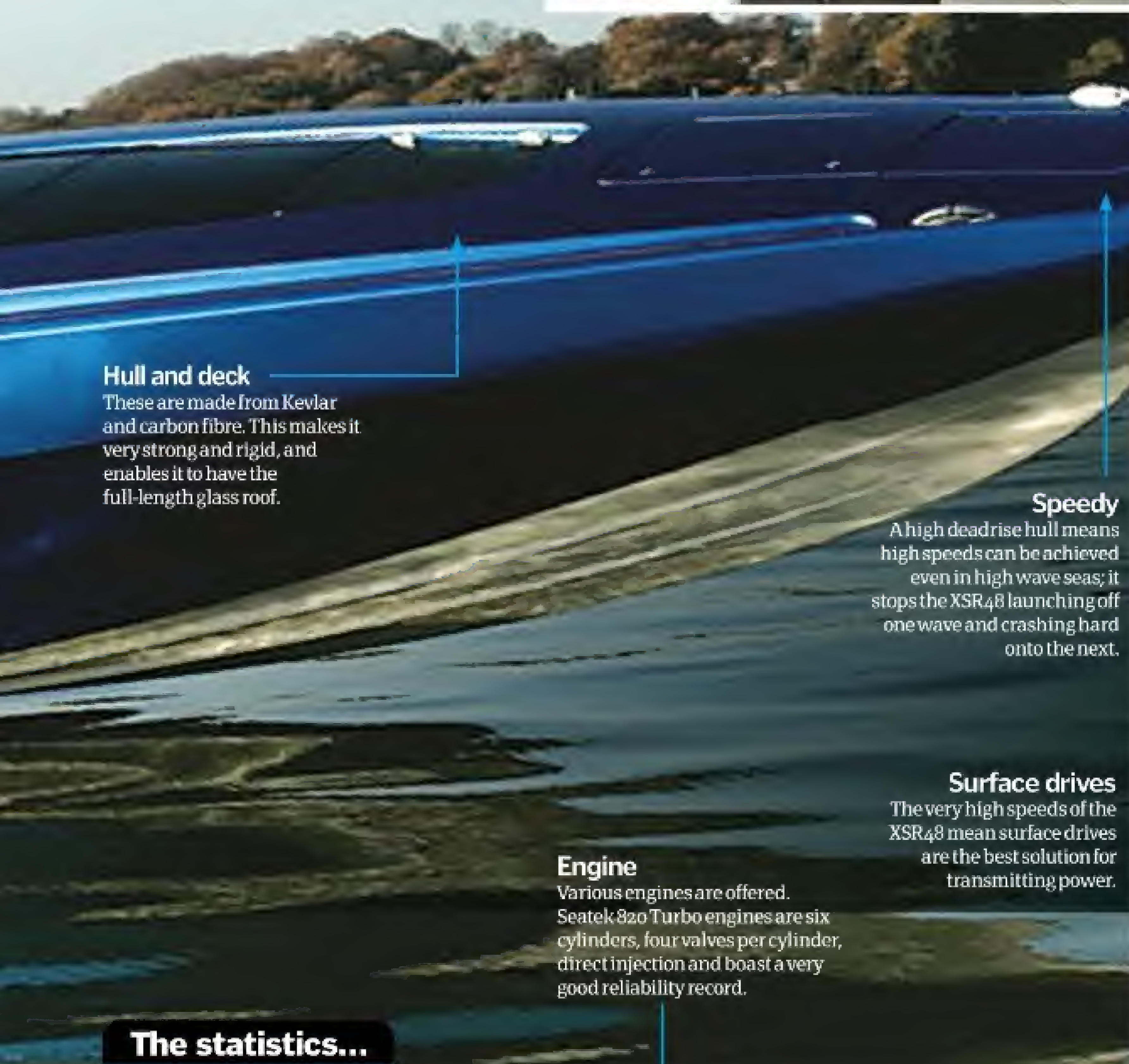
No speedboat like the XSR48 has ever existed before. It is such a revolutionary machine, a new term had to be invented: so, meet the world's first superboat! It is a true ground-breaker. Two world powerboat champions conceived this engineering marvel, and developed it with experts in naval architecture, hydrodynamics, aerodynamics, aesthetics, ergonomics and propulsion technology.

XSMG used the expertise from leading yacht designers and marine structure expertsto conceive a design. High power is essential for the superboat; the minimum output of the XSR48's twin turbodiesel engines is in excess of 1,600bhp. Countries outside Europe can also have supercharged petrol engines that give out well in excess of 2,000bhp. A 1,000-litre fuel tank carries enough diesel for a cruising range of 250 nautical miles – and this is at the XSR's cruising speed of 50-plus knots. That's more than 60mph…

This drive is delivered through a reinforced ZF gearbox to a ZF surface drive system. The surface-piercing propellers are by Rolla and made from stainless steel. Only this sort of system can withstand the potentially crushing forces that propellers could be subjected to; XSR has verified this by testing their superboat at speeds in excess of 100mph.

Given such extremes of force, shock mitigation technology had to be standardised in every seat: various configurations of race-style bucket seat are on offer to secure passengers, all of which are fitted with full race harnesses for safety purposes.

It's not all about speed, though. Because it uses a composite monocoque, the additional strength has been used to create more space inside – and the interior is overflowing with luxury. Buyers can choose, for example, a wetroom-style bathroom itself constructed from carbon fibre.



Interview Ian Sanderson CEO of XSMG

Described by Jeremy Clarkson as "the most beautiful thing created by man", the idea for the XSR48 came from CEO of XSMG Ian Sanderson. He is a speedboat master, with ten UIM international endurance powerboat records, two world titles and three European titles. "I felt that there was a huge gap in the market for an F1 car-type powerboat that could be positioned as a supercar of the sea. A 'superboat', it would be the marine equivalent of a Bugatti Veyron."

His general intent was to produce a powerboat with the technology, performance and driving experience of an F1 car. To do this, he based it on a hull that, in full racing form, can run at an incredibly impressive 140mph.

> *"I felt that there was a huge gap in the market for an F1 car-type powerboat that could be positioned as a supercar of the sea"*

Sanderson explains carbon fibre monocoque construction was used to lower the centre of gravity, provide massive strength and durability, and increase internal cubic capacity by 40 per cent compared to traditional designs. This means the cockpit and cabin are larger, fuel tanks bigger – even comfort is improved, as more equipment such as fridges and air conditioning units can be fitted.

"The hull has three transverse steps that introduce air under the boat to help her break away from the friction of the water. At each step, the V-shape of the hull is decreased from bow to stern. This means that the hull has a deep sharp V at the bow, which cuts through the waves and the back the boat runs on at high speed."

The statistics…

XSR superboat

Manufacturer: XSMG World

Unit price: £1.2 million

Dimensions: Length: 14.6m, beam: 3.19m, height overall: 3.1m, height above water: 2.2m

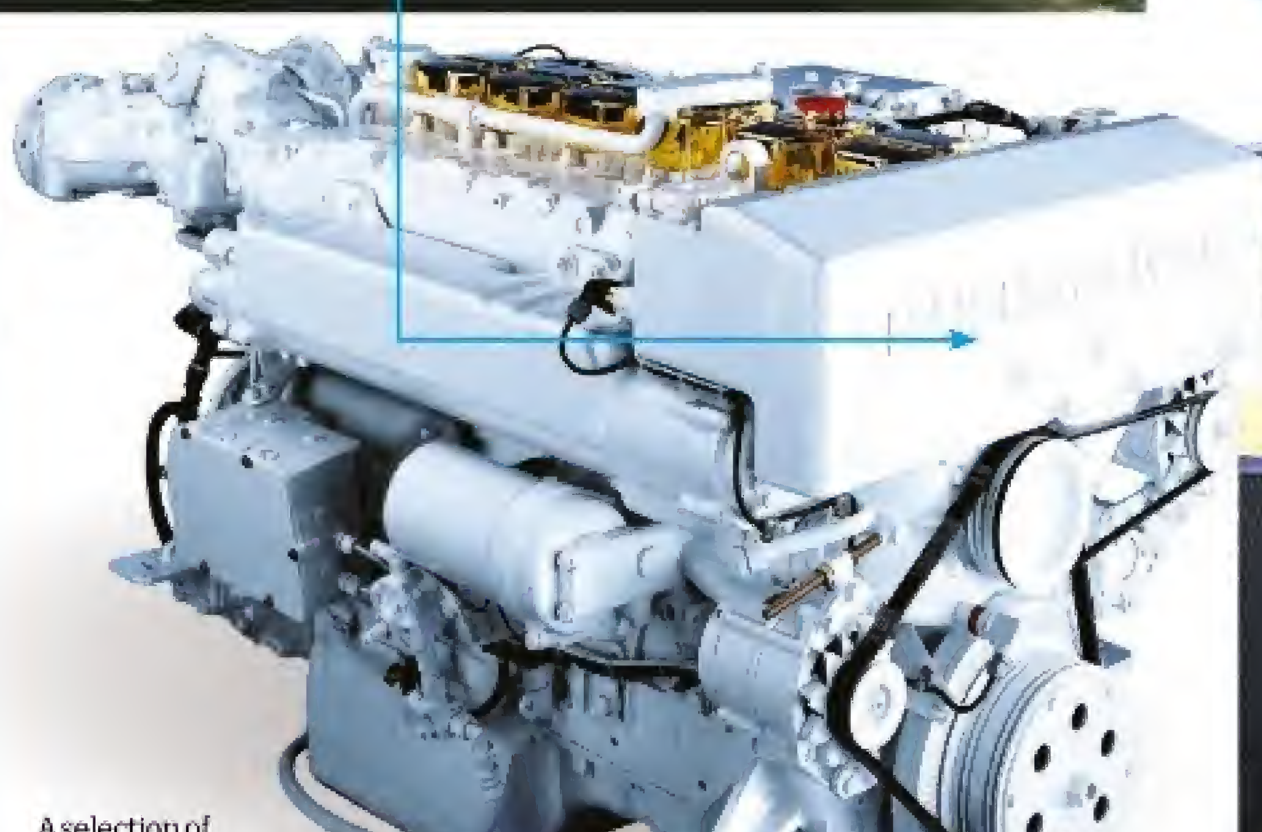
Displacement: 8,750kg

Engine: Two 10.3 L Seatek 820 Plus Turbo – 603 kW

Fuel: Diesel, capacity 1,000 litres

Top speed: 70 knots

Horsepower: 1,640bhp (standard), 1,900bhp (max)


A selection of available engines provide speeds up to 100mph

Hovercraft

How do these incredible machines traverse both land and sea?

The ability of hovercraft to cross dry land as well as water has seen them employed in the military and tourism sectors for many years. Although once billed as the next generation of transportation, they have somewhat declined in popularity over the last decade. Despite this, their usefulness is still readily apparent.

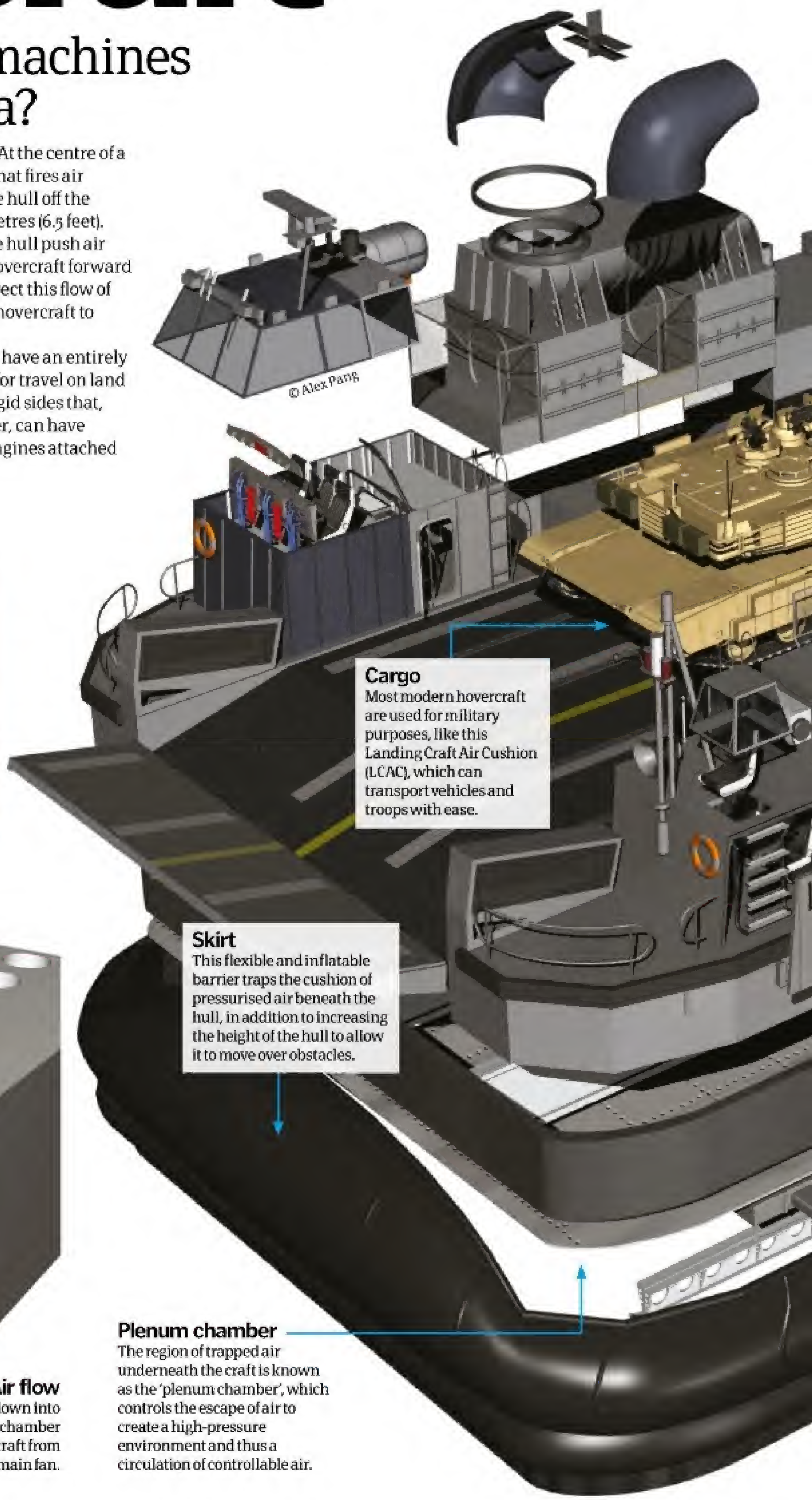
The core principle of a hovercraft is that the hull of the vehicle is suspended on top of a giant cushion of air, held in place by flexible rubber that allows it to traverse difficult terrain or choppy waves without being torn apart.

So how do they work? At the centre of a hovercraft is a huge fan that fires air downwards, pushing the hull off the ground as high as two metres (6.5 feet). Smaller fans on top of the hull push air backwards, giving the hovercraft forward momentum. Rudders direct this flow of horizontal air to allow a hovercraft to change its direction.

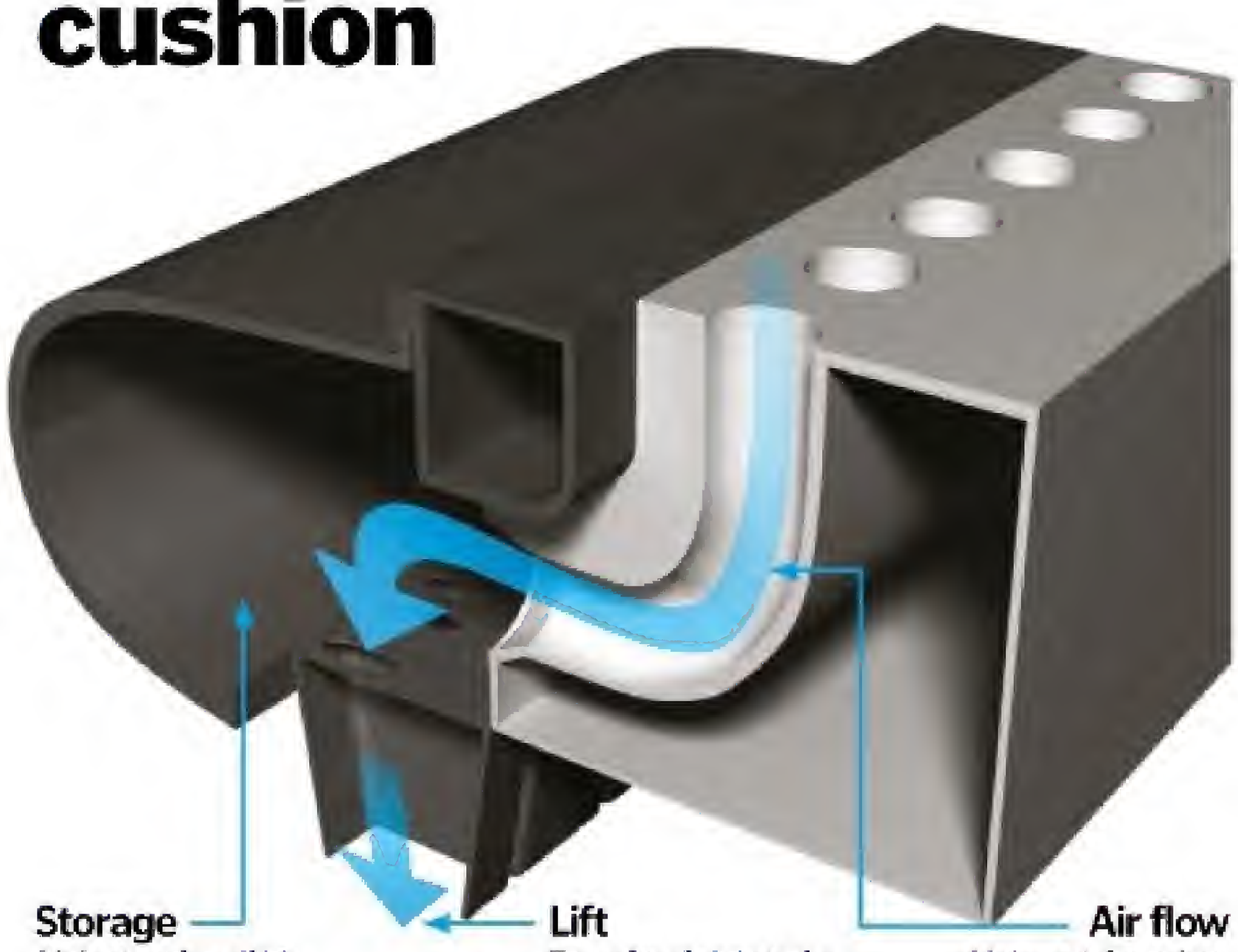
Traditional hovercraft have an entirely rubber base that allows for travel on land or sea, but others have rigid sides that, while suited only to water, can have propellers or water-jet engines attached for a quieter craft.


Hovercraft have been in use for over 50 years

© Andrew Berridge



The air cushion



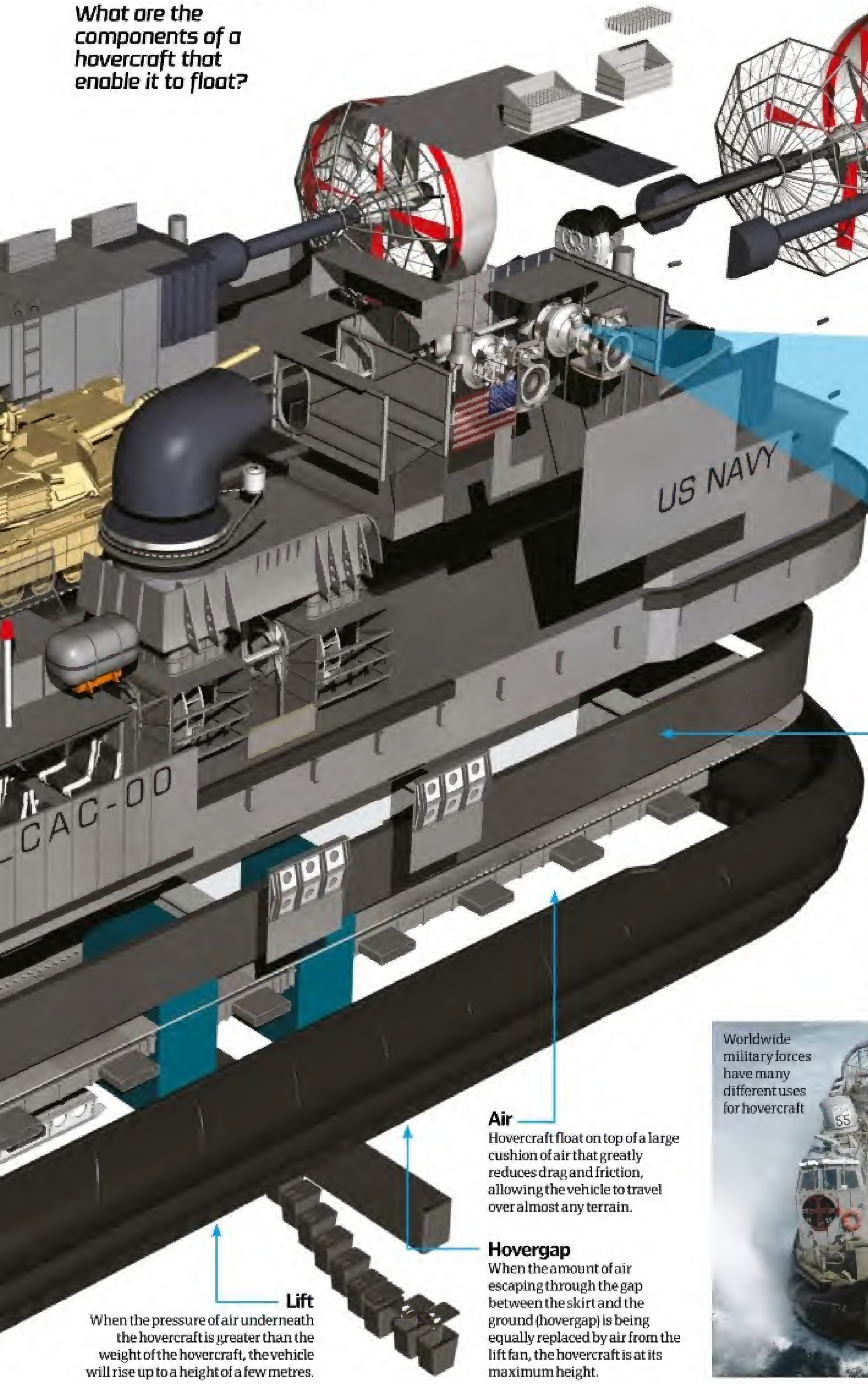
Storage
Air is stored until it's needed to give more lift, when air escapes through the hovergap.

Lift
Transfer of air into the plenum chamber increases pressure and allows the craft to rise.

Air flow
Air is sent down into the plenum chamber of the hovercraft from the main fan.

Inside an LCAC hovercraft

What are the components of a hovercraft that enable it to float?



Rudders
Flaps at the back control the hovercraft like an aircraft, directing airflow in certain directions to allow it to be steered.

Thrust fans
The hovercraft gains its propulsion from these backwards-facing fans, normally mounted on the back of the vehicle. Some use ducted fans while others favour naked propellers.

Lift fan
Air is pumped into the plenum chamber by the main fan in the centre of a hovercraft. Although some hovercraft divert air from the thrust fans instead, lift fan designs are much easier to construct.

Hull
The hull is where you'll find the driver, passengers and cargo of the hovercraft. It sits on top of the cushion of air that keeps the vehicle aloft.

Air
Hovercraft float on top of a large cushion of air that greatly reduces drag and friction, allowing the vehicle to travel over almost any terrain.

Hovergap
When the amount of air escaping through the gap between the skirt and the ground (hovergap) is being equally replaced by air from the lift fan, the hovercraft is at its maximum height.

Lift
When the pressure of air underneath the hovercraft is greater than the weight of the hovercraft, the vehicle will rise up to a height of a few metres.

Smaller hovercraft use mostly the same techniques as their larger brothers

© Ankara

Worldwide military forces have many different uses for hovercraft

HOW IT WORKS

MILITARY

The machines that shape modern warfare

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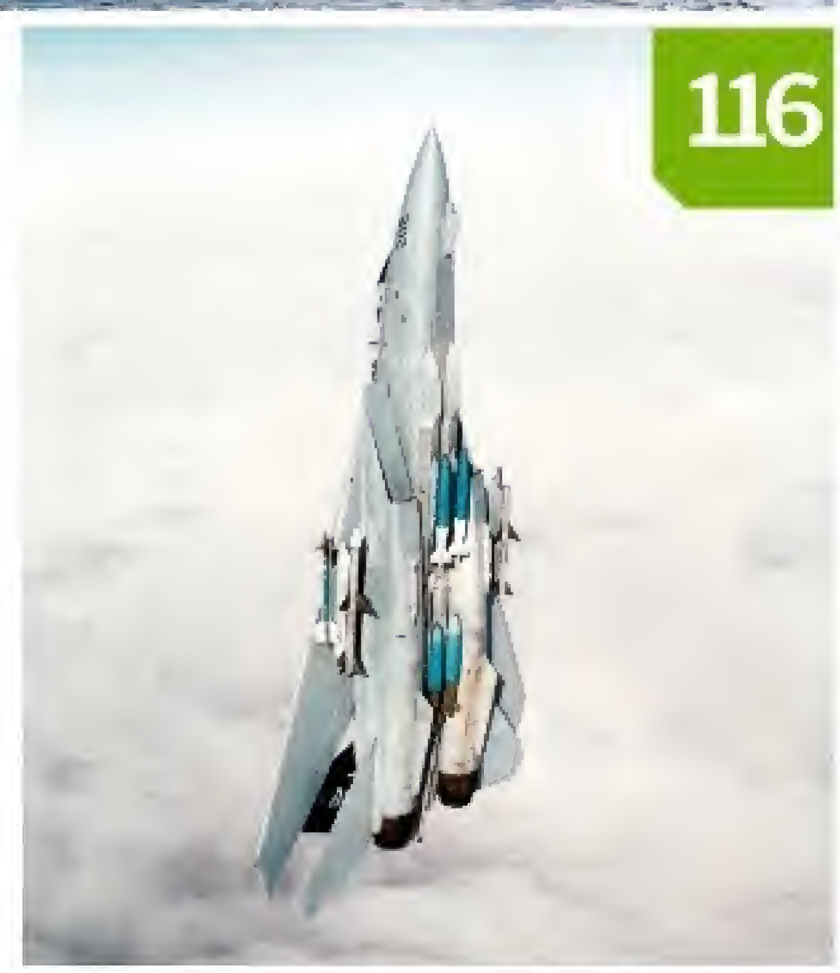

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"Discover the world's top military tech that is watching you right now from land, the seas and sky"


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SPIES IN THE SKY

THE TOP-SECRET MILITARY TECH THAT'S WATCHING YOU RIGHT NOW

Many technologies invented for the SR-71 are still in use today

On 1 May 1954, the Soviet Union's newest bomber – the Myasishchev M-4, nicknamed 'Hammer' – soared above Red Square in Moscow. It wasn't long after the successful detonation of a hydrogen bomb, and the US watched as its former World War II ally turned into a Cold War enemy.

Gaining intelligence was almost impossible, as surveillance planes that tried to enter Soviet airspace were shot down. The Lockheed U-2 would prove to be a complete game-changer. Developed at what went on to become the top secret Area 51 facility, this plane could fly out of reach of enemy fighters and missiles, taking detailed aerial photographs of airfields, factories and shipyards. Knowledge is power, and these images proved to the US that there was no immediate threat and so a deadly arms race – and potential nuclear war – was averted.

Over the course of their history, spy planes have become the most feared aircraft, despite carrying no weapons. Deployed by government and military forces, these eyes in the sky can be used for many different tasks, from patrolling borders and gathering information behind enemy lines, to monitoring battlefields for strategic decision-making.

Getting the information they need quickly and discreetly is the key aim for engineers. Modern spy planes use cutting-edge science and technology to do this, but historical planes were able to achieve amazing feats too. One such example is the SR-71 Blackbird. It was built in the analogue age, taking off in 1964 and performing reconnaissance missions until its retirement in 1990.

Despite being 32 metres long with a 17-metre wingspan, this black behemoth could fly faster than a rifle bullet, hitting Mach 3 – three times the speed of sound, over 3,700 kilometres per hour. Its distinctive curved shape with a sharp edge that ran along the body of the plane presented very few surfaces for radar detection, and using

Inside the SR-72

Blackbird's successor has a combined cycle propulsion system for reaching hypersonic speeds

"Throughout history, spy planes have become the most feared aircraft, despite carrying no weapons"

The SR-72 will reach speeds of Mach 6, double that of its predecessor

top-of-the-range photographic equipment for the time, Blackbird captured images of the ground from an altitude three times the height of Everest. Although some were lost in accidents, none were ever shot down or captured by an enemy.

Now that this godfather of spy planes is out to pasture, Lockheed Martin's Skunk Works division is developing a faster, unmanned successor, the SR-72 (nicknamed the 'Son of the Blackbird'). The engines will use a hybrid system to reach hypersonic speeds, enabling the aircraft to cross an entire continent in an hour. The air friction of this speed alone could melt steel, so the SR-72 is likely to be made of composite materials, similar to those used for space shuttles and missiles. It will need to be capable of withstanding temperatures in excess of 1,000 degrees Celsius and be sealed to stop lethal air leaks.

The technology needed to take photographs at this kind of speed will also be an incredible feat, and the exact makeup of this aircraft's gadgetry has not been confirmed, or perhaps even invented yet. What we do know is that it won't just be an observer. This new unmanned plane will be armed to the teeth, launching bombs to hit targets from altitudes of around 24 kilometres – up in the stratosphere.

Aerodynamics play a huge part in spy plane tech – aircraft like the SR-72 need to be designed to cope with stresses experienced when travelling at such high speeds. The Son of the Blackbird will need to be incredibly well balanced to deal with the changes between subsonic, supersonic and hypersonic flight to ensure that the craft is not ripped apart by the shifting centre of lift.

However, the Global Hawk, for example (an Unmanned Aerial Vehicle made by Northrup Grumman) is nothing like how you might

The SR-71 carried two crew members, but its successor is likely to be unmanned

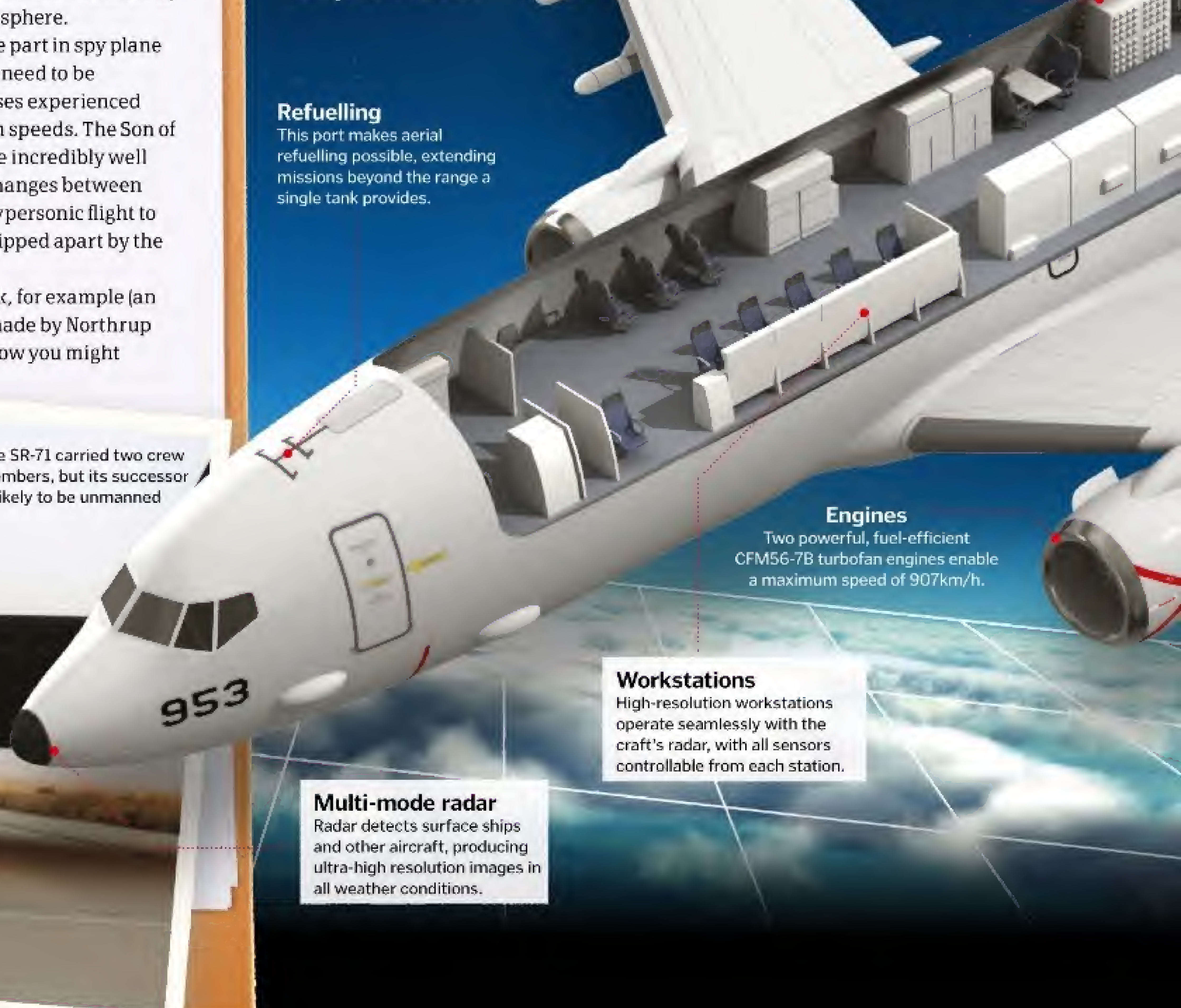
Boeing Poseidon P-8

This sky-borne sub hunter scans the waters for unwanted aquatic visitors

Based upon the tried-and-tested body of the Boeing 737-800 commercial airliner and the wings of Boeing's 737-900, the Poseidon P-8 is an advanced maritime patrol and reconnaissance aircraft. Featuring all kinds of task-specific technology, the P-8 is able to fly fast and low, cruising above the sea to seek out submarines that can pose threats to aircraft carriers.

Six extra body fuel tanks extend the plane's range to find the subs. Some variants of the Poseidon P-8 model use radar, a magnetic anomaly detector and electronic intelligence sensors to monitor telecommunications and infrared imaging to keep tabs on shipping. It can also deploy expendable sonobuoys to act as satellite sensors in the field.

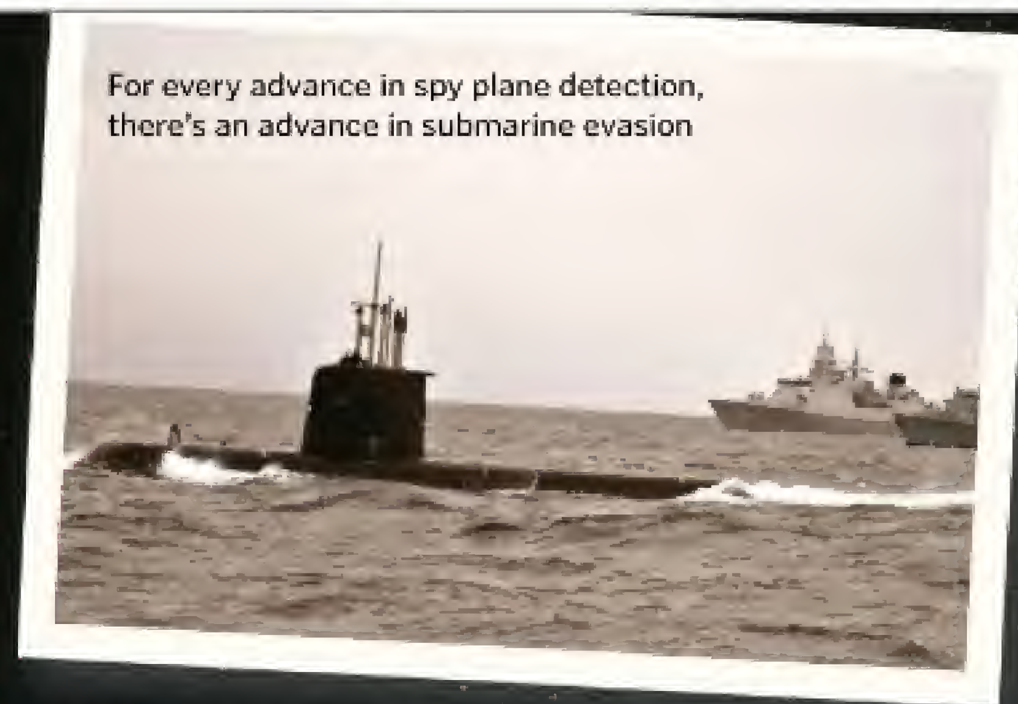
But that's not all this spy plane can do. With its strengthened fuselage, the Poseidon also boasts missiles, mines and torpedoes in its arsenal, making it ready to aim, fire and dispatch a rebel submarine if ever required.



Sonobuoys listen for sounds in the water and relay information to the aircraft

> *"With its strengthened fuselage, the Poseidon also boasts missiles, mines and torpedoes in its arsenal"*

Torpedos propel themselves towards underwater targets before detonating



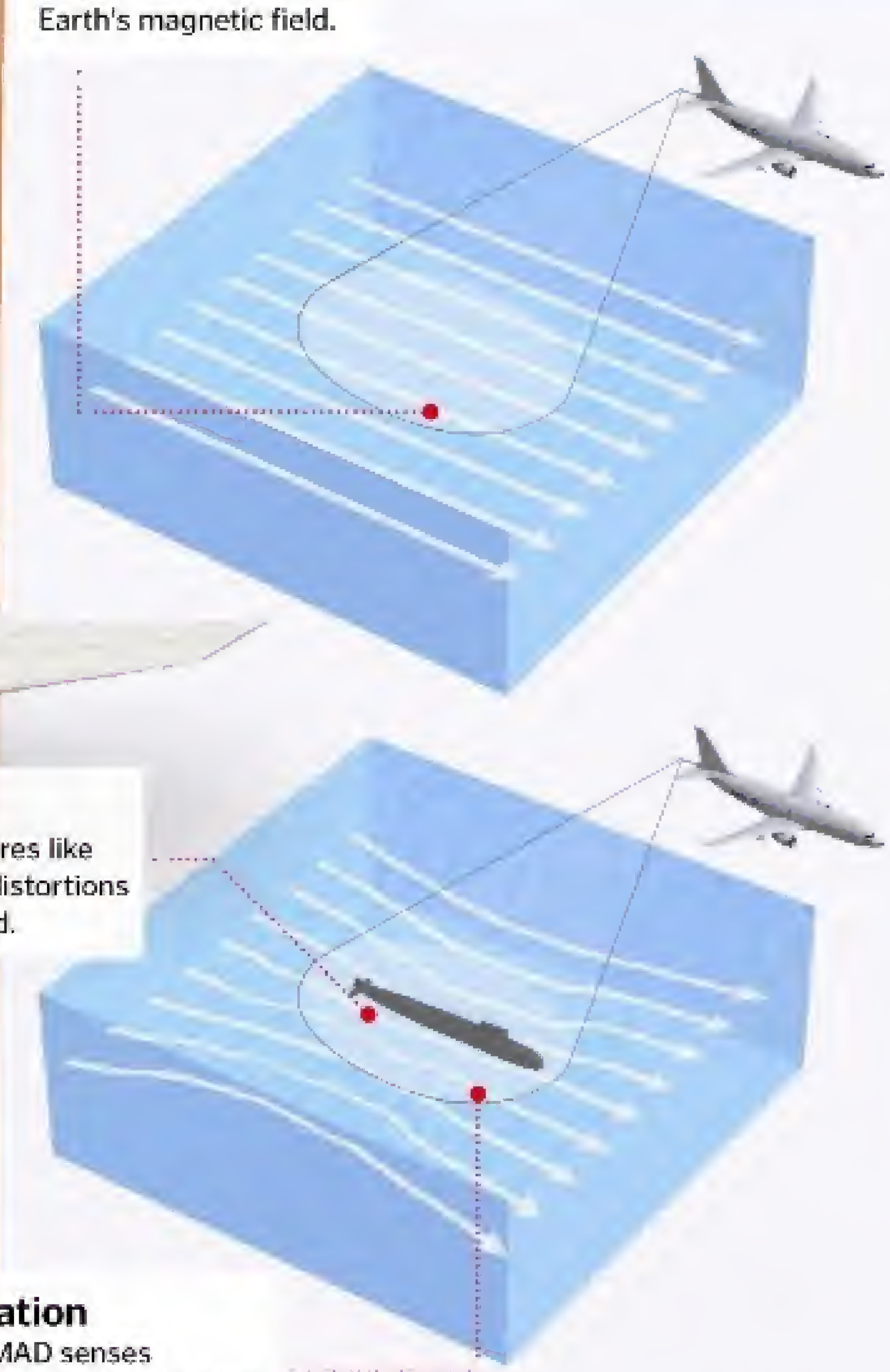
For every advance in spy plane detection, there's an advance in submarine evasion

Stealth subs

You could easily think that, for a giant metal tube in a featureless ocean, there's nowhere to hide. But once again, tech is lending a hand. Where some aircraft use magnetic anomaly detectors to seek out magnetic signatures, submarines will employ 'degaussing' techniques to evade detection. This involves using electromagnets to create another magnetic field that matches the background field, rendering the signature undetectable.

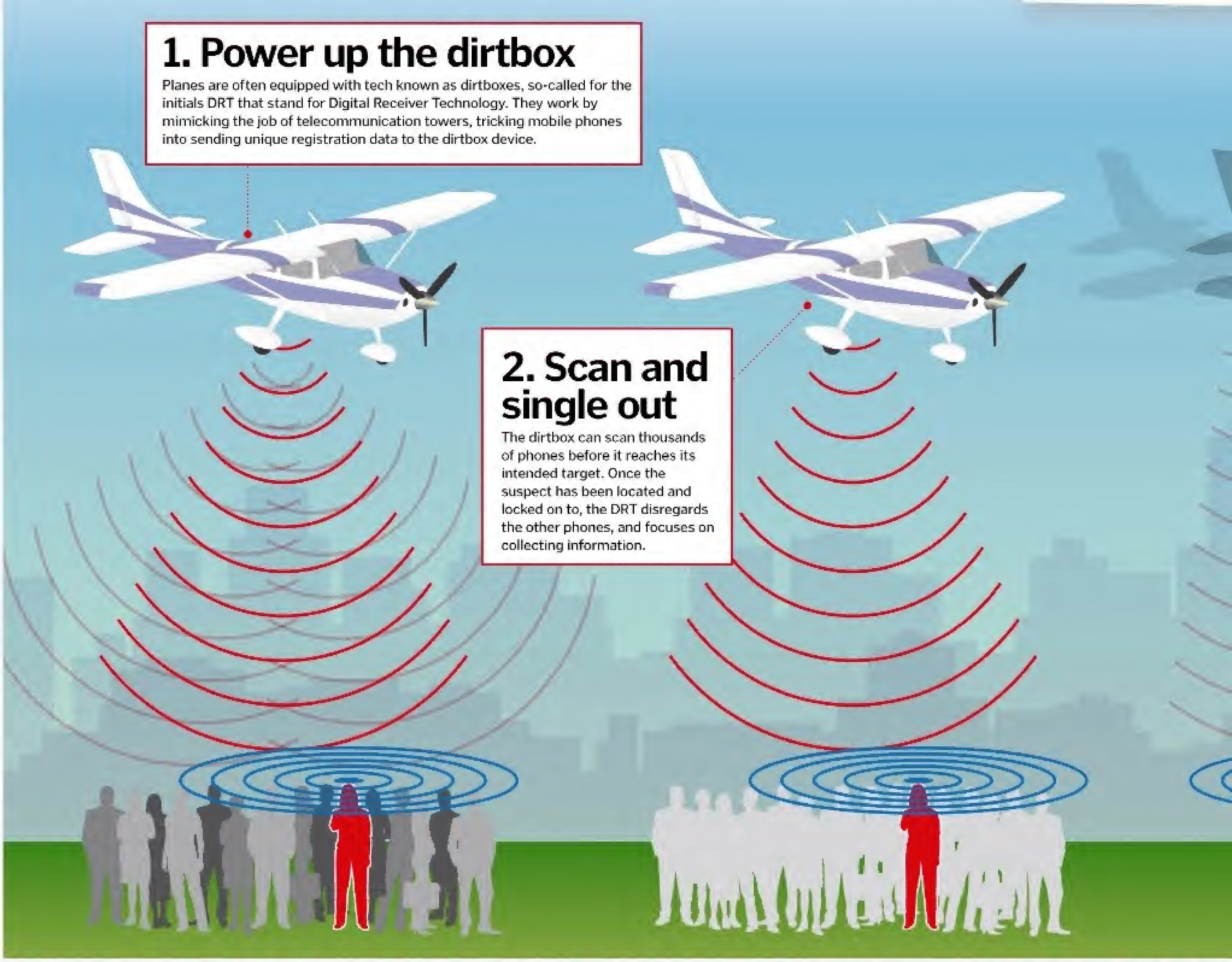
Another stealth method is to deflect sonar. Coating materials modify the sound waves hitting a submarine so that they don't bounce back. Such materials in development include a substance that 'wicks' sound waves off a sub like water off a duck's back, as well as a material that looks like miniature bubble wrap, which soaks up and disperses sound.

As sound is a big part of sub detection, one of the key ways to avoid being found is to reduce the din. All of the machinery in a submarine will be placed upon acoustic and vibration deadening buffers to minimise the overall noise of the vessel.



Surveillance strategies

The methods that spy planes use from above to find and track mobile communication signals



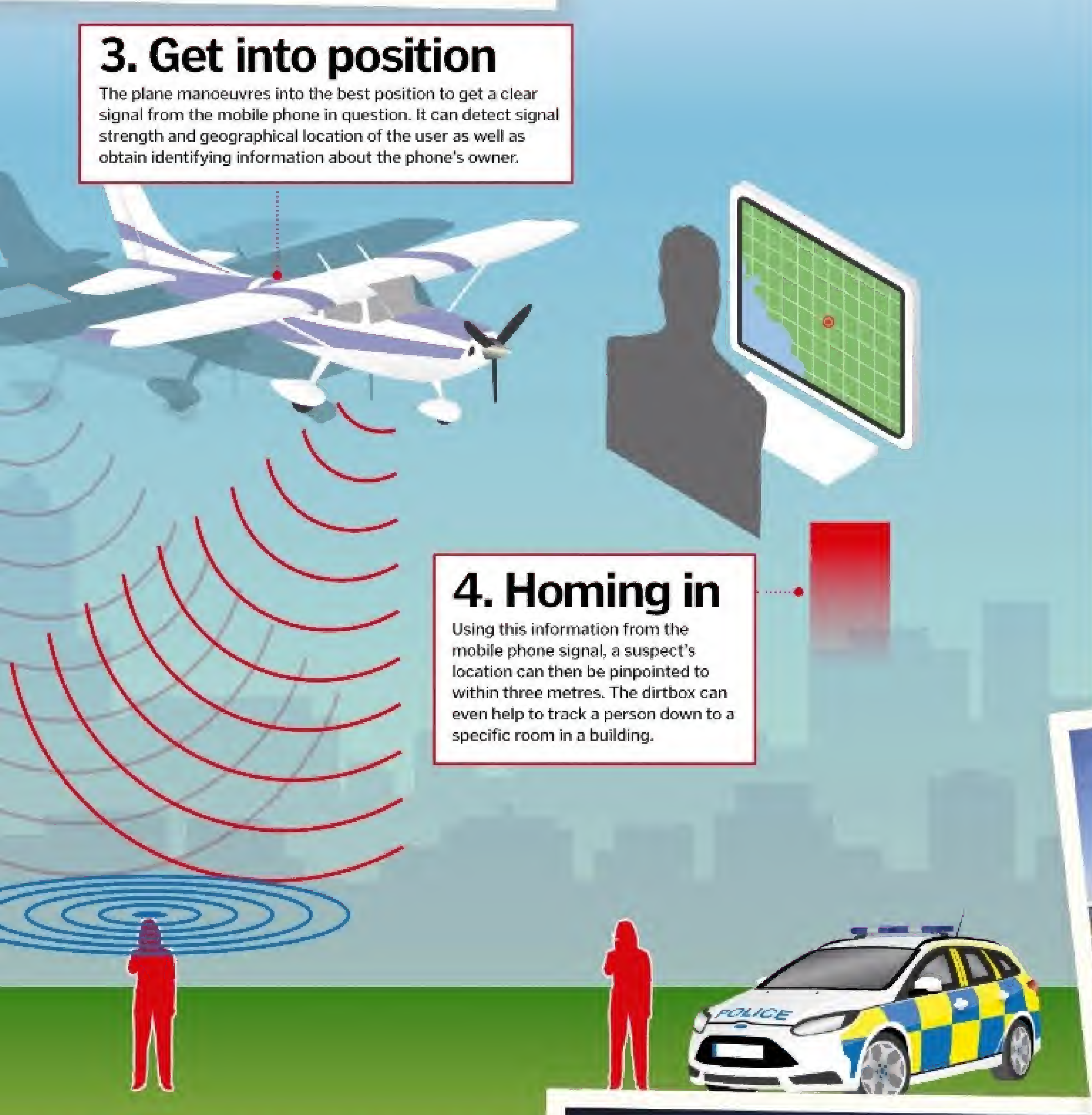
imagine a top-level spy plane to look. It has a bulging front profile and a somewhat chunky tail end, but this amazing surveillance drone is able to fly across the world to deliver real-time ISR (Intelligence, Surveillance and Reconnaissance) data to its controllers at US Air Force ground bases.

Unmanned aircraft offer numerous advantages for the advance of spy planes. First of all, engineers do not need to construct a cockpit that safeguards human life. When it comes to creating a monster machine that operates on the very edges of space, this is a money, time and space-saving bonus. The other benefit of using a spy drone instead is that it can keep going for longer than a mission with an onboard pilot. Many drones can also be pre-programmed to carry out assignments even if contact is lost with its base team.

One such spy drone causing ripples in aerial reconnaissance is Northrop Grumman's RQ-180. Not much is known about this robot apart from the fact that it exists, and that the stealth drone is designated for flying in defended airspace for spying on heavily armed rival nations. It's thought that to evade radar detection, this drone may be designed with the 'cranked kite' formation, where the shape is a fusion of the 'kite' and 'flying' wing formations. The chunky and angular shapes are designed to scatter oncoming radar waves, so that they can't be bounced back to their location and the plane can fly undetected.

The Global Hawk surveillance drone has been used in combat in Iraq and Afghanistan

"The dirtbox can scan thousands of phones before it reaches its intended target"



3. Get into position

The plane manoeuvres into the best position to get a clear signal from the mobile phone in question. It can detect signal strength and geographical location of the user as well as obtain identifying information about the phone's owner.

4. Homing in

Using this information from the mobile phone signal, a suspect's location can then be pinpointed to within three metres. The dirtbox can even help to track a person down to a specific room in a building.

The unlikely spy plane

Cessna is a company known for making light aircraft, the type that any pleasure pilot would take out for an afternoon's flight. Yet in 2015 the internet saw an explosion of reports that the FBI had outfitted some of these nondescript civilian airplanes with high-tech surveillance gadgetry.

The Cessna 182 'Skylane' is one such craft, having had the investigative force of the Bureau behind its major upgrades; the thermal imaging and infrared cameras, night vision technology plus mobile phone interceptors are just a few add-ons. These features help the FBI to follow on-going investigations targeting specific individuals, as well as support law enforcement.

These humble planes have also received high-grade makeovers from the US Air Force, who have kitted out a 182 Skylane with modifications to be used in military training exercises. The plane has all the intelligence, surveillance and reconnaissance sensors it needs to be able to mimic that of a Predator Unmanned Aerial Vehicle.

The single-engine Cessna 182 Skylane plane is proving an excellent choice for unobtrusive surveillance

As well as the shape of the aircraft, radar-absorbent materials can also be used to make them less visible. When the waves from the seeking radar hit it, these coatings can deflect the waves and send them in another direction, or in such a manner that the deflected waves cancel out the incoming ones. This renders the craft practically undiscoverable.

Stealth, speed and strength are all very well, but if a spy plane can't carry a decent payload then it's not worth its salt. There are countless

Spy planes are capable of reaching enormous altitudes

different gadgets and gizmos that can be attached, built in, added or upgraded in order to turn an ordinary military aircraft into a hub of digital sensory perception. Radar and sonar, for example, use radio and sound waves (respectively) that bounce off objects to pinpoint their location.

Reconnaissance aircraft will often carry high-resolution imaging equipment, with top-level zooms and digital video streaming and recording capabilities. Thermal imaging and infrared sensors are other payload regulars, along with a plethora of communications interceptors, acoustic monitoring and many other ways to listen in on the rest of the world. The data is delivered to analysts either onboard or on the ground via high-speed real-time links, so the intelligence gathered can be used advantageously.

It would seem that the future for ISR missions involves plenty of speed, power and altitude with the benefit of automated features. Although there are no plans to retire the old faithfuls like Lockheed's U-2 Dragon Lady just yet, there are also plenty of rumours circulating about plans for faster, meaner, more multifunctional spy planes.

One such concept is the TR-X – another Lockheed invention from their famous Skunk Works spy plane creation station in California. The planning stages are still in their infancy, but Lockheed have stated this spy plane will take the best bits of all the other great spy planes in the skies today and roll them into one mega plane that could be deployed by 2030. You could keep your eyes on the sky, but you would probably never see it coming.

The Lockheed U-2 reconnaissance plane is regarded as one of the world's top spy planes

The Lockheed U-2 cockpit is packed full of high-tech features designed to inform and assist the pilot

Lockheed U-2

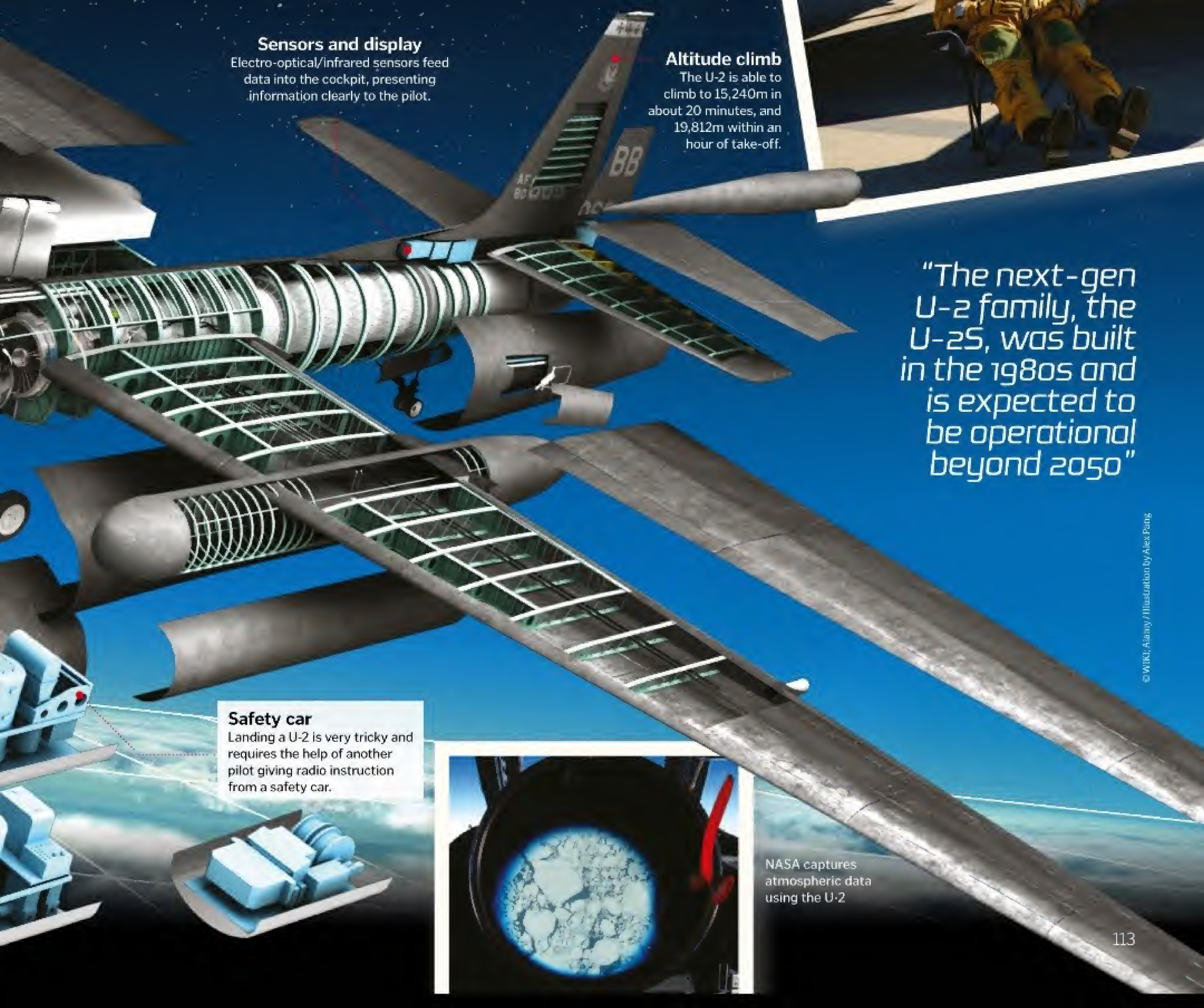
The plane that peeked around the Iron Curtain is still going strong

Named 'Dragon Lady' by the US Air Force, the U-2 was the brainchild of engineer Clarence 'Kelly' Johnson and went from design to test flight in just nine months. The slender body and long wingspan allow it to fly a range of over 4,800 kilometres at an altitude of over 21 kilometres.

The next-gen U-2 family, the U-2S, was built in the 1980s and is expected to be operational beyond 2050. These planes are fitted with state-of-the-art sensor systems that are able to collect data day and night, in all weather. The intelligence is distributed in real time for analysis and exploitation over super-fast digital links.

Today, some of the U-2's work is for NASA, equipped with various sensors to conduct atmospheric tests. U-2s have also patrolled the skies above Iraq and Afghanistan, intercepting insurgent communications and using their incredible imaging sensors to detect small disturbances on the ground, alerting troops to the presence of improvised explosive devices and mines.

U-2 pilots wear pressurised space suits to keep themselves protected when flying at high altitude



"The next-gen U-2 family, the U-2S, was built in the 1980s and is expected to be operational beyond 2050"

NASA captures atmospheric data using the U-2

You may not see the plane, but you'll see the bombs

Stealth Bomber

The B-2 is extraordinary, both in terms of appearance and design

The 'flying wing' shaped Stealth Bomber is a unique aircraft that was designed specially to make it as invisible as possible. Its shape means there are few leading edges for radar to reflect from, reducing its signature. This is further enhanced by the composite materials from which the aircraft is constructed and the coatings on its surface. These are so successful that despite having a 172-foot wingspan, the B-2's radar signature is an astounding $0.1m^2$.

The B-2's stealth capabilities, and aerodynamic shape, are further enhanced by the fact its engines are buried inside the wing. This means the induction fans at the front of the engines are concealed while the engine exhaust is minimised. As a result, the B-2's thermal signature is kept to the bare minimum, making it harder for thermal sensors to detect the bomber as well as lowering the aircraft's acoustic footprint.

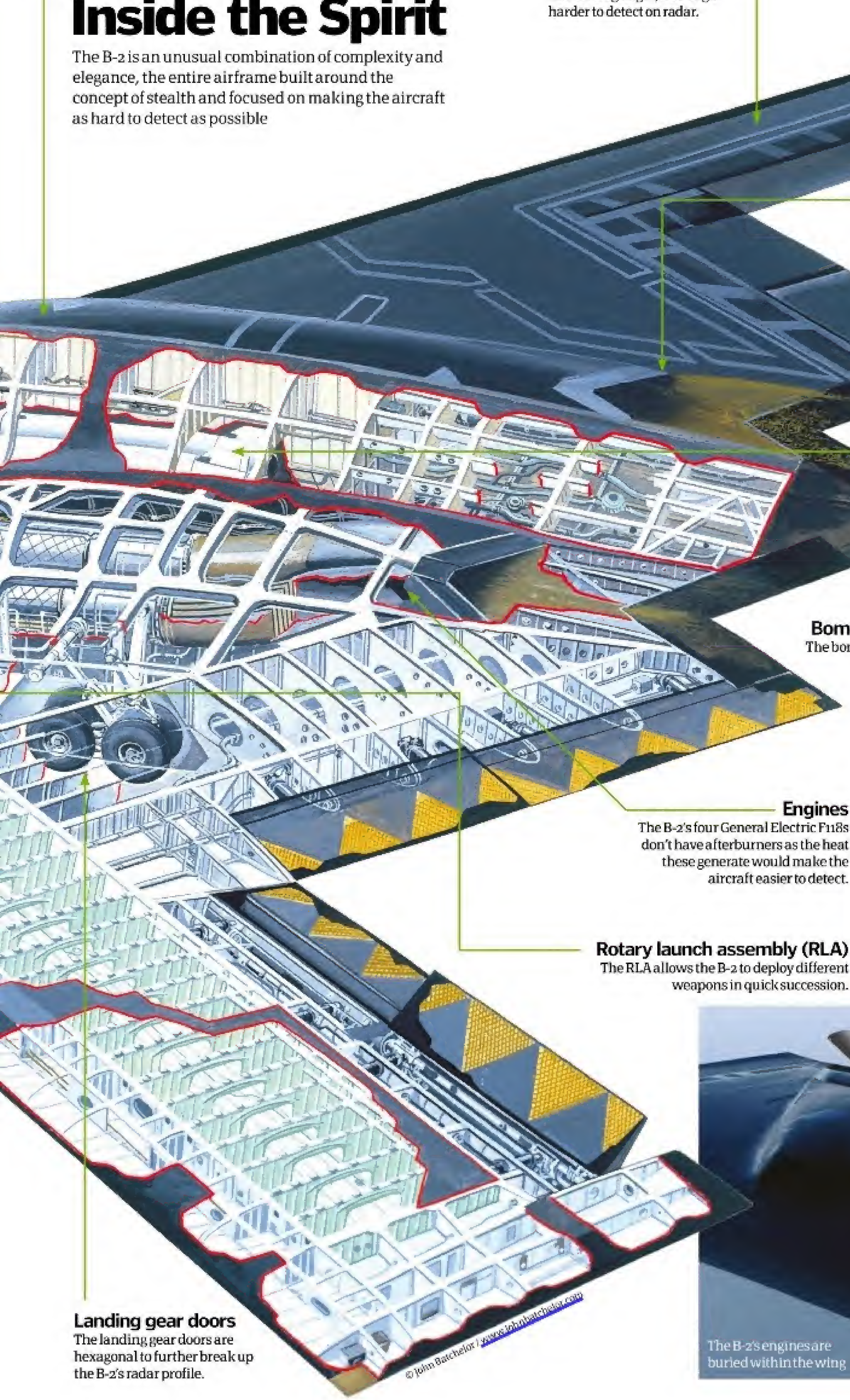
The design also means the B-2 is both highly aerodynamic and fuel efficient. The B-2's maximum range is 6,000 nautical miles and as a result the aircraft has often been used for long-range missions, some lasting 30 hours and in one case, 50. The B-2 is so highly automated that it's possible for a single crew member to fly while the other sleeps, uses the lavatory or prepares a hot meal and this combination of range and versatility has meant the aircraft has been used to research sleep cycles to improve crew performance on long-range missions.

Despite this, the aircraft's success comes with a hefty price tag. Each B-2 costs $737 million and must be kept in a climate-controlled hangar to make sure the stealth materials remain intact and functional. These problems aside though, the Spirit is truly an astonishing aircraft, even if, chances are, you won't see one unless the pilots want you to...


Not one you're likely to find in your I-Spy book...

Ghost works: Inside the Spirit

The B-2 is an unusual combination of complexity and elegance, the entire airframe built around the concept of stealth and focused on making the aircraft as hard to detect as possible



The statistics...

B-2 Spirit

Manufacturer: Northrop Grumman

Year deployed: 1993

Dimensions: Length: 69ft, wingspan: 172ft, height: 17ft

Weight empty / max: 158,000lb / 336,500lb

Unit cost: $737,000,000

Max speed: Mach 0.95 (604mph)

Propulsion: The B-2 has general Electric F118-GE-100 non-afterburning turbofans

Ceiling: 50,000ft

Armament description: The B-2 has two internal bays capable of holding 50,000lb of ordnance. Common payloads often include:
- 80 × 500lb class bombs (Mk-82) mounted on the bomb rack assembly or BRA
- 36 × 750lb CBU class bombs on BRA
- 16 × 2,000lb class weapons (Mk-84, JDAM-84, JDAM-102) mounted on the rotary launcher assembly RLA
- 16 × B61 or B83 nuclear weapons on the RLA

Landings are fine, if the tower spots you coming…

The B-2's engines are buried within the wing

F-14 Tomcat

One of the most iconic fighter jets ever built, the F-14 Tomcat dominated modern warfare for decades, delivering great performance across the wide spectrum of aerial engagement

Designed to protect the US Navy's aircraft-carrier operations at long ranges against Soviet aircraft and missiles, the Grumman Corporation-built F-14 Tomcat has been entrenched in military history and public consciousness for decades. Made famous by its numerous high-profile operations – including missions in the Vietnam, Gulf and Iraq wars – and extensive usage in the Eighties classic film *Top Gun*, the F-14 has been synonymous with prestige, advanced technology and dynamic, aggressive flight performance.

This reputation emanated from its next-generation, multi-use design, which allowed it to be utilised as both a long-range naval interceptor and air superiority fighter, making it capable of fighting in any aerial engagement. Key to this was the F-14's variable geometry wings, a sweeping system that could modify the wing position between 20 and 68 degrees depending on the nature of the operation. At high speeds, which the F-14 was capable of with great ease, the wings would be swept back, while when undertaking long-haul patrol missions at lower speeds, the wings could fully extend out, maximising its lift-to-drag ratio and improving fuel efficiency.

While in flight, its power was supplied by two Pratt & Whitney TF30 turbofans, jet engines each capable of delivering a massive 27,800 pounds of thrust with afterburners engaged. This gave the F-14 a top speed of 1,544mph (2,484kph), over twice the speed of sound, as well as a rapid rate of climb of 229 metres (751ft) a second and overall thrust-to-weight ratio of 0.91. However, due to the F-14's design brief as a multi-role aircraft, the TF30s could not only provide huge thrust but were also designed to be fuel-efficient when cruising at low speeds to maximise fuel economy.

The Tomcat was also notable for its adoption of numerous advanced electronic systems to aid flight and navigation, as demonstrated in its Central Air Data Computer (CADC) and Hughes AWG-9 X-band digital radar. The former utilised a MOS-based LSI chipset, the MP944 – one of the first microprocessor designs – and could control the primary flight system, wing sweep and flaps automatically, while the latter provided next-generation search and tracking modes that could monitor and lock onto targets hundreds of miles away.

Once enemy targets had been discovered, the F-14 was more than capable of taking them down, fitted to counter every aspect of air combat. Missiles included the formidable AIM-54 Phoenix, a long-range air-to-air missile system, as well as both the AIM-9 Sidewinder and AIM-Sparrow III systems to deal with short- and medium-range targets. Air-to-ground options were also not in short supply (the F-14 was adopted late on in its service period as a bomber) with JDAM precision-guided munitions, the Paveway series of laser-guided bombs and the MK 80 and MK 20 series of iron bombs capable of being fitted to one of its ten hardpoints. Finally, the F-14 was installed with the ferocious M61 Vulcan six-barrelled gatling cannon, a system capable of firing over 6,000 20mm rounds every 60 seconds.

Wings could be fully extended for long-haul missions

The statistics...

F-14 Tomcat

Crew: Two

Length: 19.1m (62.6ft)

Wingspan: 19.55m (64ft)

Height: 4.88m (15.7ft)

Weight: 19.83m (65ft)

Powerplant: Two x General Electric F110-GE-400 afterburning turbofans

Max thrust: 13,810lbf

Max speed: Mach 2.34 (1,544mph/2,484kph)

Combat radius: 575mi/ 925km

Max altitude: 15,200m (49,868ft)

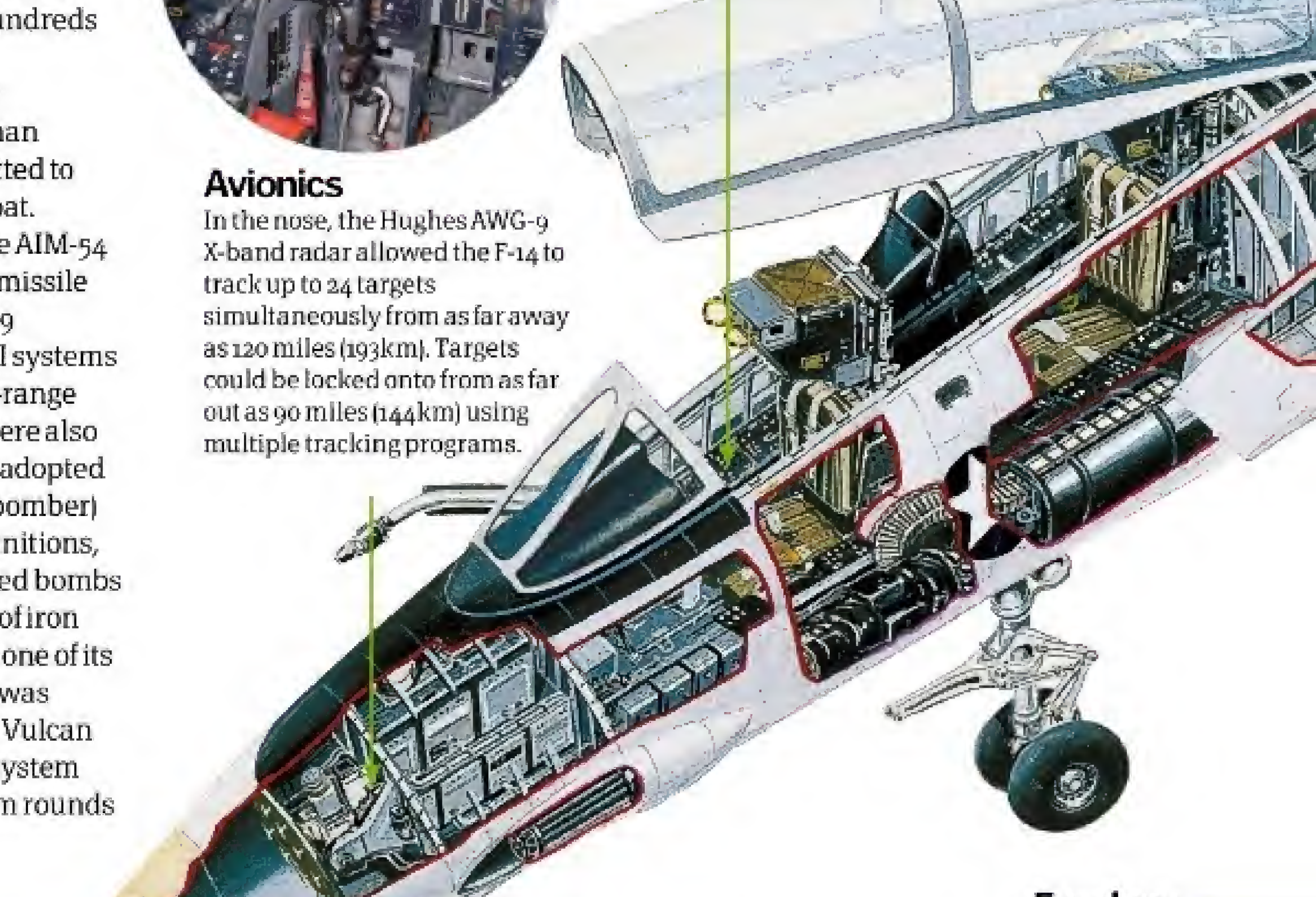
Armament: One x 20mm M61 Vulcan gatling cannon

Hardpoints: 10 (six under fuselage, two under nacelles, two on wing gloves)

Missiles: AIM-54 Phoenix, AIM-7 Sparrow, AIM-9 Sidewinder

Bombs: JDAM, Pavewave, Mk 80, Mk 20 Rockeye II

Cost: $38 million



Avionics

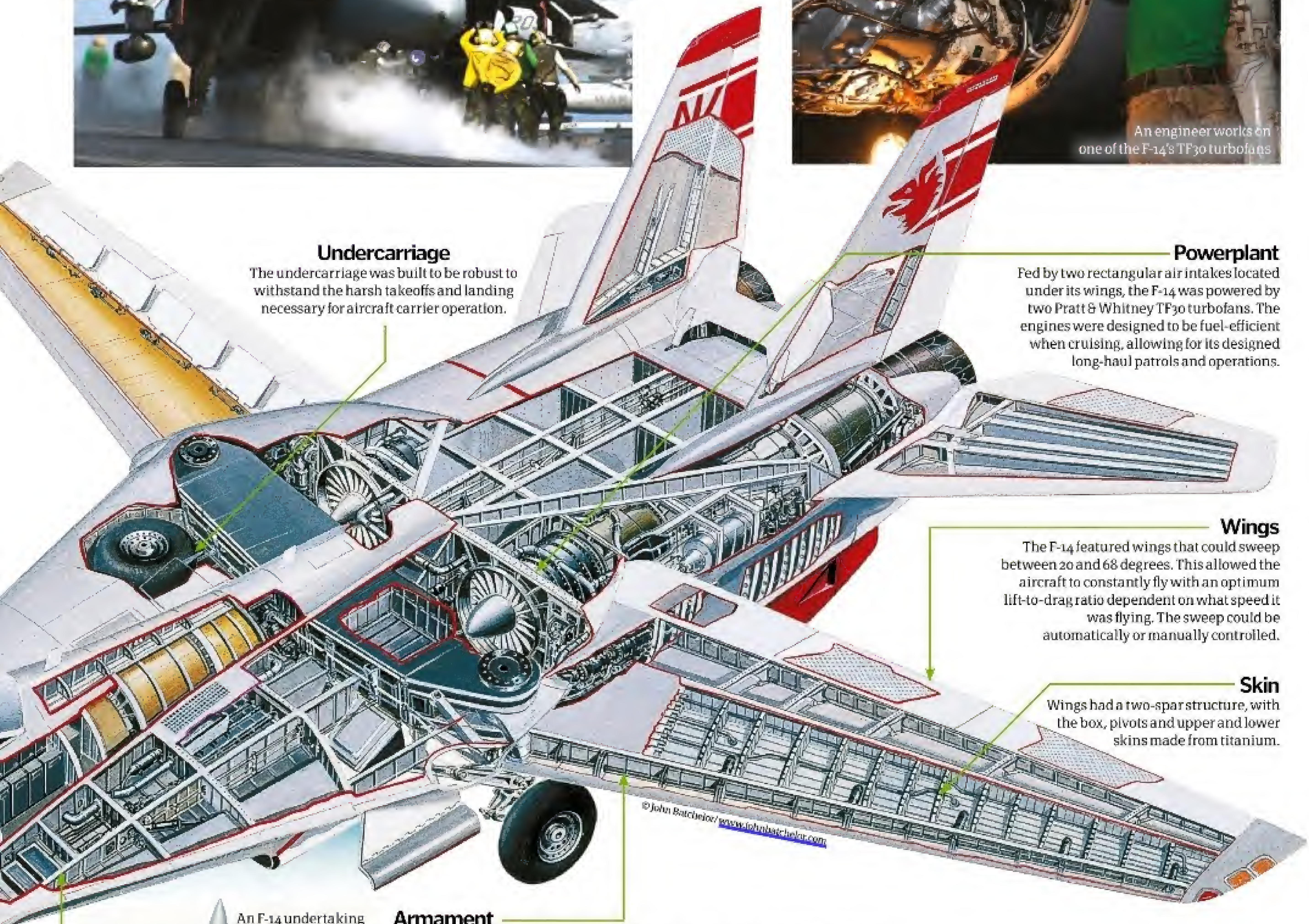
In the nose, the Hughes AWG-9 X-band radar allowed the F-14 to track up to 24 targets simultaneously from as far away as 120 miles (193km). Targets could be locked onto from as far out as 90 miles (144km) using multiple tracking programs.

Fuselage

The distinguishing feature of the F-14's fuselage was its large flat area between the engine nacelles, referred to as the 'pancake'. This area provided over half the F-14's total aerodynamic lifting surface and housed the fuel tanks, flight controls and wing-sweep mechanisms.

"Umm guys, I'm trying to take off here..."

An engineer works on one of the F-14's TF30 turbofans



Undercarriage

The undercarriage was built to be robust to withstand the harsh takeoffs and landing necessary for aircraft carrier operation.

Powerplant

Fed by two rectangular air intakes located under its wings, the F-14 was powered by two Pratt & Whitney TF30 turbofans. The engines were designed to be fuel-efficient when cruising, allowing for its designed long-haul patrols and operations.

Wings

The F-14 featured wings that could sweep between 20 and 68 degrees. This allowed the aircraft to constantly fly with an optimum lift-to-drag ratio dependent on what speed it was flying. The sweep could be automatically or manually controlled.

Skin

Wings had a two-spar structure, with the box, pivots and upper and lower skins made from titanium.

Armament

The F-14's standard layout included a single long-range air-to-air AIM-54 Phoenix, two short-range air-to-air AIM-9 Sidewinders, two air-to-air AIM-7 Sparrow IIIs and an M61 Vulcan autocannon capable of firing 6,000 rounds per minute.

An F-14 undertaking a vertical climb

The insane M61 Vulcan autocannon

An F-14 flying over Iraq during the Gulf war

ARMED & DANGEROUS

ATTACK HELICOPTERS

THE DEADLY GUNSHIPS ELIMINATING THE ENEMY FROM ABOVE

The AH-64 Apache is one of the most iconic and successful attack helicopters

"Many new gunships were constructed as the Cold War escalated"

The V-280 Valor will attempt to make attack helicopters faster and stronger than ever before

The modern attack helicopter is the complete military machine. Cutting through the air with titanium blades, loaded up with missiles and a cockpit full of advanced technology; they are true terrors of the sky. A tank's worst nightmare, the rise of attack helicopters has revolutionised the battlefield.

The idea of rotary wing military aircraft was first toyed with during the early years of World War II but it wasn't until 1942 that they reached prominence. That year the US War Department proposed a new idea. It was called 'organic Army aviation' and, separate from the Air Corps, it was tasked with developing helicopters. Various new designs, including the revolutionary Sikorsky R-4, were created but it took until the Korean War for helicopters to really take off. Infantry and cargo could now be ferried in and out of battle rapidly and invasion forces could engage the enemy much more effectively from the air. Helicopters were integral to US operations in the rough terrain of Korea and by the time of the Vietnam War, the iconic Bell UH-1 Iroquois was used extensively. The 'Huey' ushered in a new era of air cavalry, as helicopter weaponry became more sophisticated.

Military helicopters were also designed to serve in a purely offensive capacity and the attack helicopter was born. Many new gunships were constructed as the Cold War escalated. These included the American Piasecki H-21 and Bell AH-1 Cobra and the Russian Mil Mi-24. In 1986, the Boeing AH-64 Apache emerged as a template that other armed forces tried to replicate, and helped bring an end to the dominance of tanks on the battlefield. As more breeds of attack helicopter took to the skies, it became clear that these versatile vehicles could assist the military in many ways. This led to the advent of dual and multi-role helicopters.

In recent years, attack helicopters have been equipped with ever more advanced systems that have improved efficiency, aerodynamics and performance. The array of tech on offer is truly astonishing, but there is still room for further progress. Join us as we examine what's on offer for the future of the world's best attack choppers.

Types of military helicopter

Choppers are an essential part of modern warfare, from reconnaissance to attack

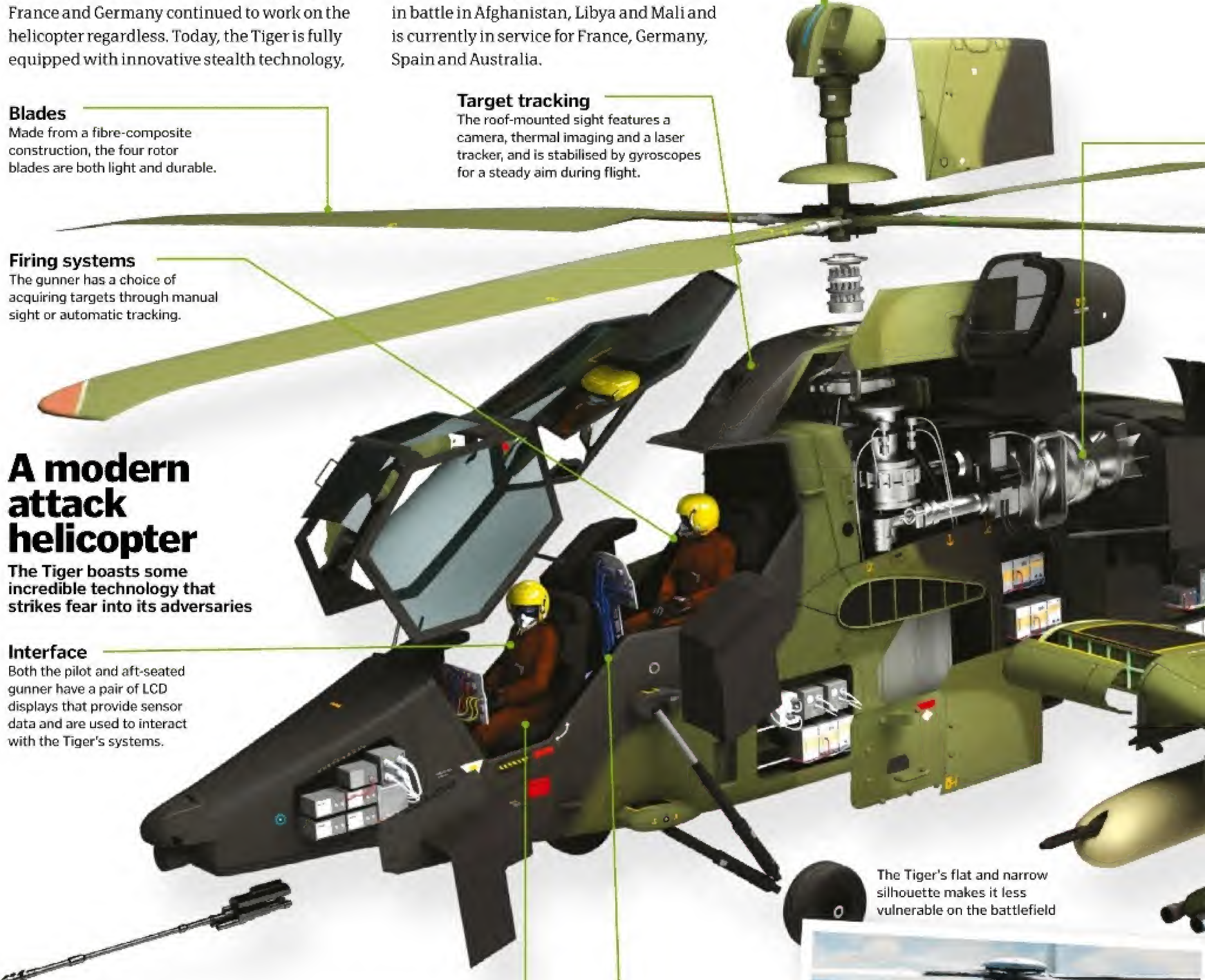
The Tiger

The all-action attack gunship that is a key player in modern aerial warfare

A heavy-hitting, relentless attack dog, the Airbus Helicopters Tiger has both the armament and performance capabilities to dominate the battlefield. During the Cold War, it was developed in order to respond to any potential attacks on Western Europe by the USSR. The subsequent collapse of the Soviet Union meant it never saw active battle service in that era, but France and Germany continued to work on the helicopter regardless. Today, the Tiger is fully equipped with innovative stealth technology, highly accurate GPS systems, and electronic countermeasures. It specialises in anti-tank missions but the Tiger's flexibility means that it can handle a variety of roles. The image below is of an HAD combat helicopter but other models include the UHT multi-role fire support, ARH Armed Reconnaissance and HAP combat support. It has been deployed in battle in Afghanistan, Libya and Mali and is currently in service for France, Germany, Spain and Australia.

A modern attack helicopter

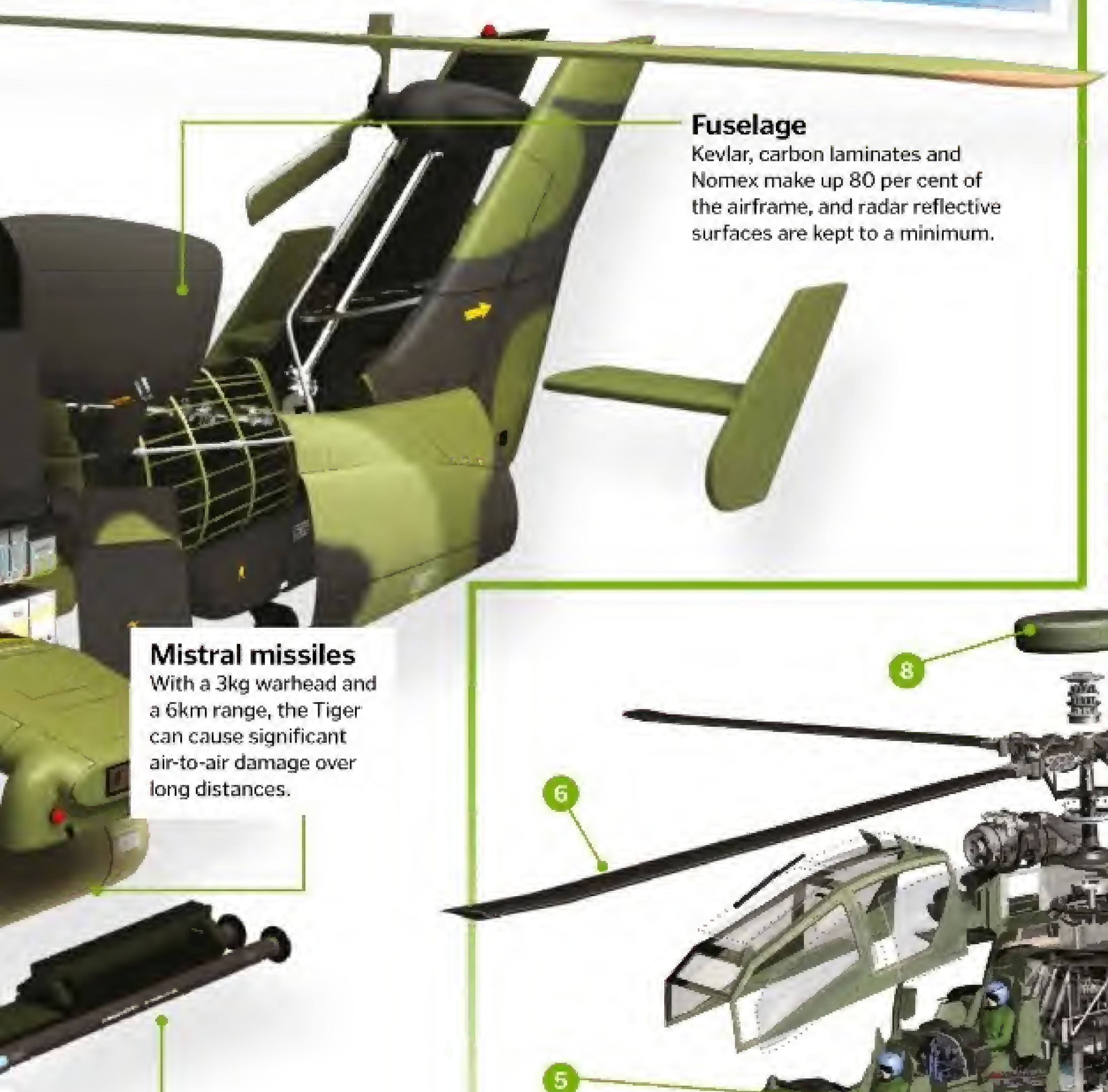
The Tiger boasts some incredible technology that strikes fear into its adversaries



"The fuel tanks are self-sealing and explosion suppressive"

The Tiger's flat and narrow silhouette makes it less vulnerable on the battlefield

An AH-64D fires its flares as a countermeasure against infrared missile seekers



Power
The Tiger is powered by two 960kW turboshaft engines. The fuel tanks are self-sealing and explosion suppressive when exposed to enemy fire or in the event of a crash.

Fuselage
Kevlar, carbon laminates and Nomex make up 80 per cent of the airframe, and radar reflective surfaces are kept to a minimum.

Mistral missiles
With a 3kg warhead and a 6km range, the Tiger can cause significant air-to-air damage over long distances.

Weaponry
The Tiger can be fitted with different combinations of weapons depending on the variant, suitable for both air-to-ground and air-to-air combat.

AH-64D Apache Longbow

An iconic gunship that's still a capable attack chopper

The AH-64D Apache Longbow gunship is arguably the most famous multi-mission attack helicopter of the modern age. Over the past 19 years of service, it has proven itself both combat-ready and reliable in numerous theatres of conflict.

The AH-64D was upgraded in 2008 to include increased digitisation, a joint tactical radio system, enhanced engines and drive systems, the capability to control UAVs (unmanned aerial vehicles) – which were used extensively in the Iraq and Afghanistan wars – along with improved landing gear. Currently, the Apache AH-64D Longbow is operated by the US, Egypt, Greece, Israel, Japan, Kuwait, the Netherlands, China, Singapore and the United Arab Emirates, with many other countries operating older Apache variants.

1 T700-GE-701C engines
The turboshaft engines allow the AH-64D Longbow to reach a cruise speed of 284km/h.

2 Automatic cannon
The 30mm automatic cannon is capable of firing large, highly incendiary rounds.

3 Hellfire missiles
These laser-guided missiles are effective at taking down enemy armour and structures.

4 Explosive rockets
Fast firing 70mm rockets allow the Apache to support ground troops in any assault on enemy soldiers, strongholds or vehicles.

5 Cockpit
With room for two, the Apache's cockpit allows excellent battlefield visibility with wide viewing angles.

6 Composite rotor blades
A composite four-blade main rotor allows for increased payload, climb rate and cruise speed over earlier variants.

7 Fuselage
Designed for manoeuvrability and stealth, the fuselage is painted in camouflaged colours.

8 Radar dome
This system enables target detection from behind obstacles.

The Bluecopter

Introducing Airbus' eco-efficient demonstrator – a game-changer that could make choppers more stealthy

The Bluecopter has allowed Airbus to test innovative, eco-friendly technologies

Stealth helicopters

How tech can help make choppers a whole lot quieter

One of a military helicopter's biggest strengths is its manoeuvrability. Being able to take off and land in difficult terrain, move in any direction and hover makes gunships incredibly useful in battle. However, this advantage comes at a price and the sound of the rotor blades spinning almost negates any chance of a stealthy approach. Helicopter blades are noisy because of blade-vortex interaction (BVI). Each blade rotates at such a speed that high amounts of turbulence are caused. Huge amounts of air flow around the blades as they turn and a concentrated vortex (a whirling mass of air similar to a whirlwind) is formed. As each following blade cuts through this vortex, acoustic energy and vibrations are created, resulting in the classic chopper sound. It has been a long-standing issue but now various technologies are being implemented in an attempt to reduce it.

Airbus' Bluecopter has a new style of rotor blade that utilises Blue Edge technology. The innovative double-swept design reduces noise by four decibels by reducing the surface area of the blade that impacts on the vortex. This is complemented by Blue Pulse technology, which incorporates three flap modules into every blade. Directed by a flap rotor control that uses tiny electric motors powered by crystals, they move at up to 40 times a second, lessening the BVI as less pressure is created. This decreases the level of noise generated, as well as giving the pilot a smoother ride with a significant reduction in cabin vibrations.

Another method the Bluecopter is using to make it both greener and stealthier is a Fenestron. This encases the tail rotor and allows the mechanism to have more blades, which adds more thrust, while reducing drag and vibration. On the Bluecopter, stealth technology is used in conjunction with aerodynamic landing skid fairings and a T-tail stabilising rudder to increase efficiency and decrease emissions.

> "The innovative double swept design reduces noise by up to four decibels"

Operation Neptune Spear

On 1 May 2011, US President Barack Obama declared to the world that Osama bin Laden had been killed. The operation that disposed of the founder of Al-Qaeda was codenamed Operation Neptune Spear and was undertaken in two Black Hawk helicopters supported by two MH-47 Chinooks. During the mission, one of the Black Hawks ran into difficulty and had to make a hard landing. It was reported that before leaving, the SEALs made efforts to destroy the downed chopper, leading aviation analysts to believe they were equipped with secret stealth technology. US authorities have remained tight-lipped on the matter, but photos of the surviving wreckage appeared to show modifications to the tail section to suppress noise and avoid radar.

The UH-60 Black Hawk has become the US Army's premier multi-role helicopter

Types of military helicopter missions

Powerful, agile and resilient, the Tiger is the chopper of choice in many situations

Ground fire support

Infantry and armoured divisions on the ground can rely on the Tiger to provide backup. The 30mm gun is incredibly accurate and can fire at a maximum distance of 2,000m.

Amphibious operations

The Tiger HAD is also a worthy adversary at sea. It was designed to be able to land on aircraft and its low maintenance requirements mean it can stay out at sea for long periods.

Escort

Operations in Afghanistan, Libya and Mali allowed the Tiger to display its prowess as an escort chopper. It can easily eliminate threats and guide others to safety.

Armed reconnaissance

Day and night identification sensors make the Tiger a highly competent reconnaissance unit that can weave through tough terrain and also engage the enemy if it needs to.

Aerial combat

The twin attack power of a 30mm turreted gun and Mistral missiles are more than a match for any other helicopter. Also on board are 32 chaff and flare cartridges.

Anti-tank warfare

The range of powerful anti-tank missiles at the Tiger's disposal make it the ideal gunship. It can take out tanks from a safe distance, firing from up to 8,000m away.

Ask the expert

We spoke to Marius Bebesel, programme manager at Airbus to explain more about the Bluecopter

What sort of helicopter is the Blucopter?
Based on an H135, the Bluecopter technology demonstrator is a light, twin-engine helicopter. It is a flying technology test bed, on which Airbus Helicopters is able to trial next-generation eco-friendly technologies that can be applied across Airbus Helicopters' product line. The Blucopter is a unique, one-of-a-kind, test aircraft.

How environmentally friendly and energy efficient is it?
The Bluecopter allowed Airbus Helicopters to test performance and fuel management technologies (including an 'eco-mode', which shuts down one of the two engines during standard cruise) leading to a ten per cent reduction in fuel consumption, helping to achieve a 40 per cent CO_2 emissions reduction.

The demonstrator features several design measures to reduce the aerodynamic drag of the helicopter. This includes fairings for the main rotor hub and the landing skids, and a newly developed low drag aft-body concept.

The eco-friendly approach is extended even to the attractive paint scheme of the helicopter, which makes use of the latest water-based paint technologies.

Do you have plans for any electric helicopters?
Airbus Helicopters is researching lower emissions technology with its compound helicopter LifeRCraft and the High Compression Engine (using an advanced diesel engine instead of a turbine for light helicopters).

Airbus Group has teamed up with Siemens to research electric flight. It is thought that by 2030 passenger aircraft below 100 seats could be propelled by hybrid propulsion systems.

The innovative technologies used on the Raider allow it to reach much higher speeds than standard choppers

Military helicopters: the next generation

What does the future have in store for a new class of supercopter?

While the Boeing AH-64 Apache and the Sikorsky UH-60 Black Hawk are still capable gunships, even more advanced updates are on the horizon. Both companies are at the forefront of future helicopter design and are aiming to develop choppers that will boast twice the speed and twice the range of the current crop. The two aviation giants are currently joining forces to create the SB>1 Defiant while Bell and Lockheed has its own rival project in the shape of the V-280 Valor. Both ventures are demonstrator aircraft and will act as trial runs to potential future helicopter designs under the Future Vertical Lift (FVL) project. They will take to the skies for testing as part of the US Army's Joint Multi-Role programme in early 2017. FVL includes five all-new helicopters that will replace the current designs with a new breed of attack copter. As well as having first-class combat capabilities, the new helicopters will embrace semi-autonomous technology and be flexible enough to serve in urban security, disaster relief and medical evacuation. Each of the aircraft will use a new active system that will advise the crew on when components in the cockpit need to be replaced, while also giving as much assistance as possible to the pilot. Compatibility with other vehicles will be at the forefront of the new choppers' design. They will be capable of landing on ships and being stored on cargo planes. These ultra-advanced helicopters are set to be in production by 2030 and will serve the US Army, Navy, Air Force and Marine Corps.

> "The new helicopters will embrace semi-autonomous technology"

As well as attack helicopters, the classic Chinook design will also be getting an overhaul.

DID YOU KNOW? *The S-97 Raider unofficially broke the copter speed record in 2010 and is designed to reach speeds of 407km/h*

SB>1 Defiant

Sikorsky and Boeing's joint venture could help change the face of helicopter technology

The Block II Chinook programme will see Boeing's iconic twin rotor vehicles undergo a modernisation project. They will still utilise the same basic design but will be kitted out with an assortment of modern technology. All the projects are a fascinating glimpse into the future and will build on the already cutting-edge technology used in today's helicopters. While drones continue their vital role on the front line of aerial combat, the attack helicopter will once again dominate the skies with more advanced engineering and weaponry than ever before.

The Raider's cockpit can fit two pilots and the cabin will have space for six soldiers

S-97 Raider

Sikorsky is currently developing a new generation of helicopter. Utilising innovative technology, the S-97 Raider has not one but two coaxial counter-rotating rotors. These rotors are mounted on the same shaft but rotate in opposite directions. This advanced rotor-wing technology will be accompanied by a push propeller at the rear and will enable the vehicle to reach altitudes of 3,000 metres even in the most challenging climates, travelling at twice the speed of the fastest helicopters currently in the air. As well as its superior performance, the Raider is designed to have a reduced turning radius and lower sound emissions than current helicopters. Its likely role within the military will be as a light tactical vehicle but it still packs a punch and comes equipped with Hellfire missiles. The Raider will be equally adept at armed reconnaissance and search and rescue missions and comes complete with retractable landing gear, vibration control and thermal management systems for this purpose.

The Raider conducted its maiden flight in 2015 and is currently still under development

AJAX armoured fighting vehicles

Discover the sophisticated vehicles that will serve as the Army's eyes and ears in battle

Imagine being a soldier in a war zone and your transport sustains damage to its armour from enemy fire. You'd probably have more confidence in your chances of survival if you knew the damaged component could be replaced there and then. That's one of the principles behind the design of AJAX, the British Army's latest armoured reconnaissance vehicle. Due to enter service in 2017, AJAX has some of the most advanced battlefield surveillance technology available.

Versatility and flexibility are key elements of its design. In addition to the base model, there are five variants that have been engineered for different objectives. Since each is based on AJAX, all share that vehicle's modular armour system and what is called scalable Electronic Architecture. Put another way, important hardware and software can easily be replaced or upgraded if they are damaged or superseded by better components.

It's not just the protective shielding and computer systems that are state-of-the-art though. AJAX has a 40-millimetre cannon that can fire five types of projectile. These can be side-loaded to leave more room in the cab for a crew of up to four and a supply of spare parts and ammunition.

AJAX has been designed to play a central role in the British Army's contribution to Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR). This integrated international approach is intended to help commanders make better combat decisions.

General Dynamics will supply 589 AJAX vehicles at a cost of £3.5 billion ($4.4 billion)

AJAX variants

Five adaptations of AJAX that will have their own special assignments

ARES

Designed to transport a crew of two for surveillance close to enemy targets, the ARES has a Remote Weapon System.

ATLAS

Built to rescue casualties, the ATLAS is fitted with a recovery package that includes two winches and an anchor.

ARGUS

The focus of this two-person vehicle is engineering-relevant data such as the topography of the surrounding landscape.

ATHENA

The ATHENA's onboard mapping and surveillance equipment will be used to synchronise decision-making.

APOLLO

The APOLLO variant comes equipped with a crane and towing equipment for recovering damaged vehicles.

Unconventional ammunition

The rounds fired by the cannon are comparatively small and can travel up to 1,500 metres per second.

Firepower

The 40mm telescoped cannon can fire training, airburst high explosive, aerial airburst, armour piercing and point detonating rounds.

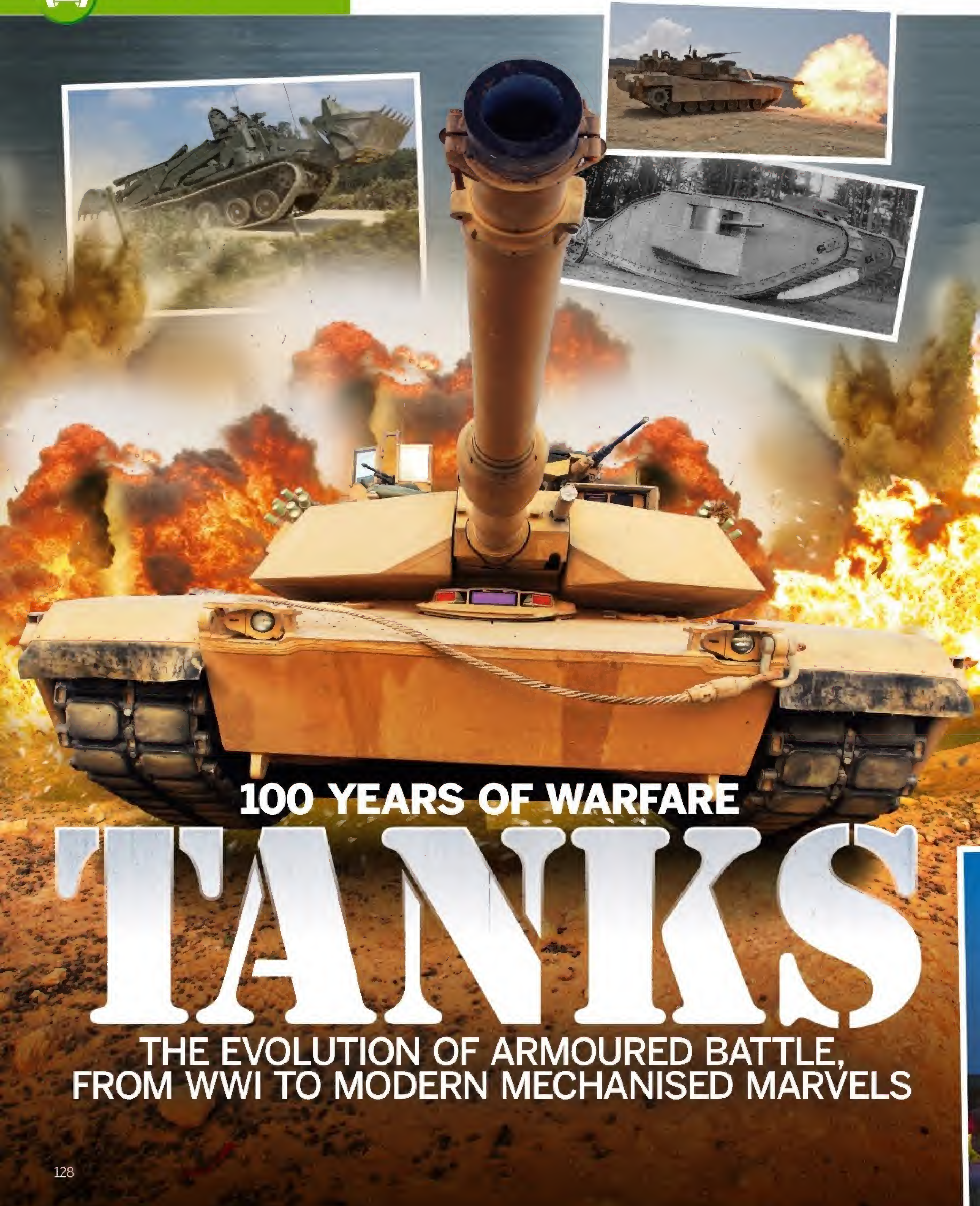
Diesel engine

The 805-horsepower diesel engine gives the AJAX a top speed of over 70km/h.

Load bearing

Classed as a 'medium-weight' vehicle, AJAX can operate under a total weight of up to 42 tons.

"Versatility and flexibility are key elements of the AJAX design"



100 YEARS OF WARFARE

TANKS

THE EVOLUTION OF ARMOURED BATTLE, FROM WWI TO MODERN MECHANISED MARVELS

Ancient Greek hoplites joined their shields and advanced in unison. Hannibal's Carthaginians mounted war elephants. The visionary Leonardo da Vinci rendered an image of an armoured fighting vehicle in 1487. While the concept of the tank - an armoured unit that could dominate the battlefield - has existed for almost as long as mankind has waged war, it became workable and developed to devastating capability 100 years ago.

Since the creaky bathtubs of World War I, the tank has existed to provide an operational edge during combat. Its varied roles range from the hammer blow of the mailed fist to break through enemy lines, to the rapid exploitation of the breach and the destruction of other vehicles and fortifications, as well as reconnaissance and fire support as mobile artillery.

To successfully complete the assigned mission, tanks require three key design elements: firepower, mobility and protection. Concentrated firepower punches a hole through enemy lines, while being able to tackle any type of terrain at speed enables them to travel over enemy trenches, and heavy armour shields the crew that supplies the expertise, efficiency, and courage to go in harm's way.

When the tank entered combat for the first time, hopes were high that the horrific stalemate of trench warfare would be broken. While the tank matured as an armament system, it became a weapon of dominance and decision. Today, the tank is perceived both as a potential war winner and a costly machine that may be past its prime. Regardless, the technological advancements and its impact on warfare are nothing short of astonishing.

Without question, the mere existence of the tank continues to influence any decision to wage war and any effective defence against an attacker on land. The tank, therefore, remains a prime shaper of military strategy and will continue to be into the foreseeable future.

Tanks through time

Over decades of warfare, technology has shaped tanks into weapons of awesome power

Mark V (Male)
Country of origin: United Kingdom
First produced: 1917
Still in service? No

Char B1 bis
Country of origin: France
First produced: 1937
Still in service? No

Centurion
Country of origin: United Kingdom
First produced: 1945
Still in service?: No

M60
Country of origin: United States
First produced: 1959
Still in service? Yes

PT-76
Country of origin: Soviet Union
First produced: 1950
Still in service? Yes

T-54
Country of origin: Soviet Union
First produced: 1948
Still in service? Yes

T-72
Country of origin: Soviet Union
First produced: 1971
Still in service? Yes

Leopard 2
Country of origin: Germany
First produced: 1979
Still in service? Yes

M1A1 Abrams
Country of origin: United States
First produced: 1979
Still in service? Yes

Challenger 2
Country of origin: United Kingdom
First produced: 1993
Still in service? Yes

Arjun
Country of origin: India
First produced: 2004
Still in service? Yes

K2 Black Panther
Country of origin: South Korea
First produced: 2013
Still in service? Yes

T-90
Country of origin: Russia
First produced: 1993
Still in service? Yes

The T-72 tank has been exported to over 30 countries

Challenger 2 is equipped with a highly accurate fire control system

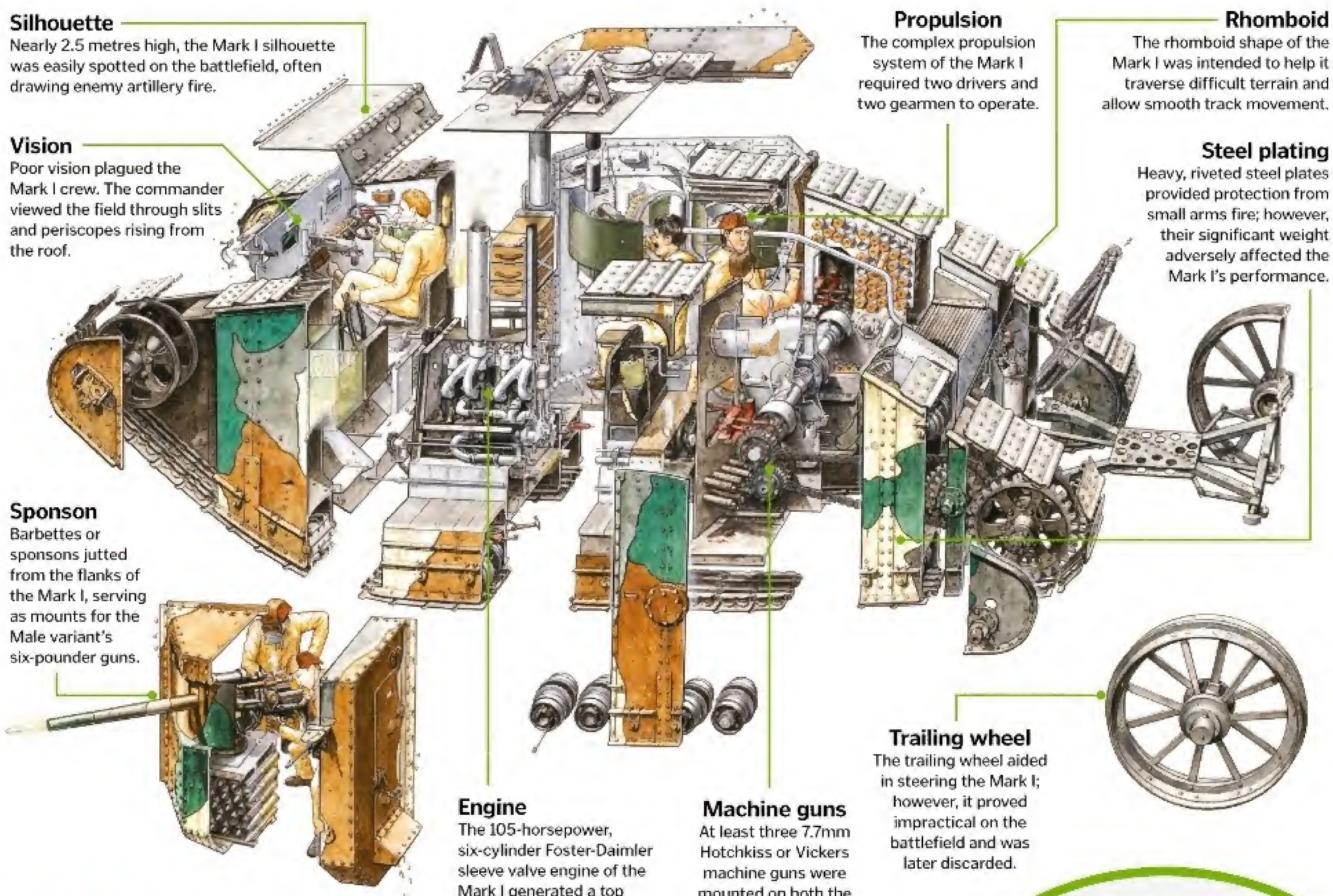
Tanks past and present

How the demands of the modern battlefield have shaped designs

Prior to World War I, research and development yielded some practical benefits in tank design. Caterpillar treads, already in use with heavy tractors, proved superior to wheels, and power to weight ratios were recognised as having significant impact on mobility and performance.

Experimentation with every aspect of the tank's development led to the introduction of basic internal power plants, and sheets of steel were riveted together to form armoured boxes on top of a tractor or car chassis. Visibility and steering were crudely accomplished with hazardous viewing ports and a series of tillers respectively. Machine guns and cannon originally meant for use with infantry and artillery units were also adapted.

Although they were terrifying to the common foot soldier that encountered them, the earliest



1916

Mark I The first tank ended the stalemate of trench warfare

Hopes of breaking the agonising stalemate of trench warfare during World War I led to the accelerated development of the world's first operational tank, the British Mark I. The Landships Committee was established in 1915 by Winston Churchill – First Lord of the Admiralty at the time – to produce an armoured vehicle for the battlefield. The Mark I was the production model of earlier prototypes Little Willie and Mother.

The Mark I weighed just over 28 tons and was powered by a six-cylinder Foster-Daimler engine. It was produced in two variants, the Male mounting two Hotchkiss six-pounder guns and the Female mounting two Vickers machine guns, with both variants sporting an additional three light machine guns.

Eight crewmen shared a common compartment. The British Army placed the first order for 100 Mark I tanks in February 1916, and the tank made its combat debut during the Battle of the Somme. Although several tanks broke down or became stranded, a new era in modern warfare had begun.

A fleet of 36 tanks led an attack at the 1916 Battle of Flers-Courcelette

tanks were heavy and unwieldy contraptions that were prone to mechanical failures. The engines were simply inadequate for propelling the tremendous weight of the vehicle forward. The exhaust fumes from straining engines sometimes even sickened the crews so seriously that they could not function.

The second generation of armoured vehicles reflected the experience of the Great War, and numerous innovations of the interwar years were put to use during World War II. The purpose-built tank chassis was refined, diesel and gasoline engines became more powerful and some were borrowed from the aircraft industry. The rotating turret-mounted machine guns and cannons were introduced and armour protection improved, while communication between tanks was vastly enhanced with reliable radios that replaced hand signals and directional flags.

During the second half of the 20th century and beyond, evolving technology has transformed the tank into a modern marvel of mechanised warfare. Global Positioning Systems (GPS) foster unprecedented coordination of units, while sophisticated infrared target acquisition and stabilisation equipment allow tanks to track multiple targets simultaneously and accurately fire weapons on the move. They also feature state-of-the-art turbine engines combined with composite armour – lighter and many times stronger than steel – for unprecedented speed and security.

Conditions inside a Mark I were hot, noisy and dangerous for the eight-man crew

An American crew awaits orders for a light tank in Coburg, Germany in 1945

M4 Sherman tanks equipped with flame-throwers were deployed by the US in the Battle of Iwo Jima in 1945

The first tanks were designed to break through barbed wire on enemy lines

PRESENT DAY

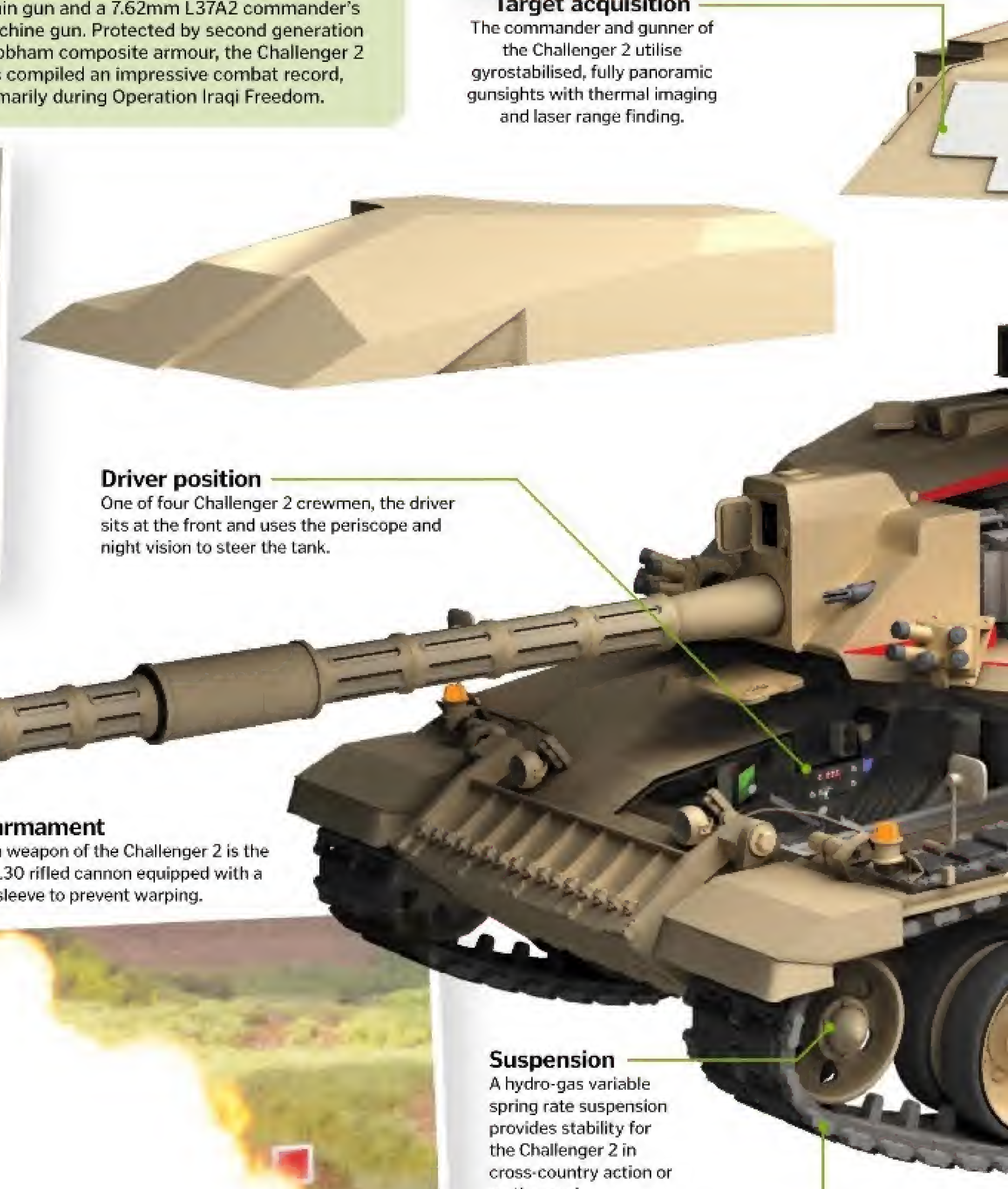
Challenger 2 The main battle tank of the British Army

Considered by many military analysts to be the finest main battle tank in the world today, the development of the British Challenger 2 occurred during a five-year period from 1986 to 1991. Although it shares a common name with its predecessor, the Challenger 1, less than five per cent of the components are compatible.

Designed as a battlefield supremacy tank, the Challenger 2 weighs just under 70 tons and is the first British tank since World War II to be designed, developed, and put into production by a single principal defence contractor, the Land Systems Division of BAE Systems. The main weapon of the Challenger 2 is the 120mm L30 CHARM (CHallenger main ARMament) rifled gun, and control of the turret and gun are maintained through solid-state electronics.

The tank is also equipped with smaller weapons, including a coaxial L94A1 7.62mm chain gun and a 7.62mm L37A2 commander's machine gun. Protected by second generation Chobham composite armour, the Challenger 2 has compiled an impressive combat record, primarily during Operation Iraqi Freedom.

The British Challenger 2 was produced from 1993 to 2002, and approximately 450 units were completed



Target acquisition
The commander and gunner of the Challenger 2 utilise gyrostabilised, fully panoramic gunsights with thermal imaging and laser range finding.

Driver position
One of four Challenger 2 crewmen, the driver sits at the front and uses the periscope and night vision to steer the tank.

Main armament
The main weapon of the Challenger 2 is the 120mm L30 rifled cannon equipped with a thermal sleeve to prevent warping.

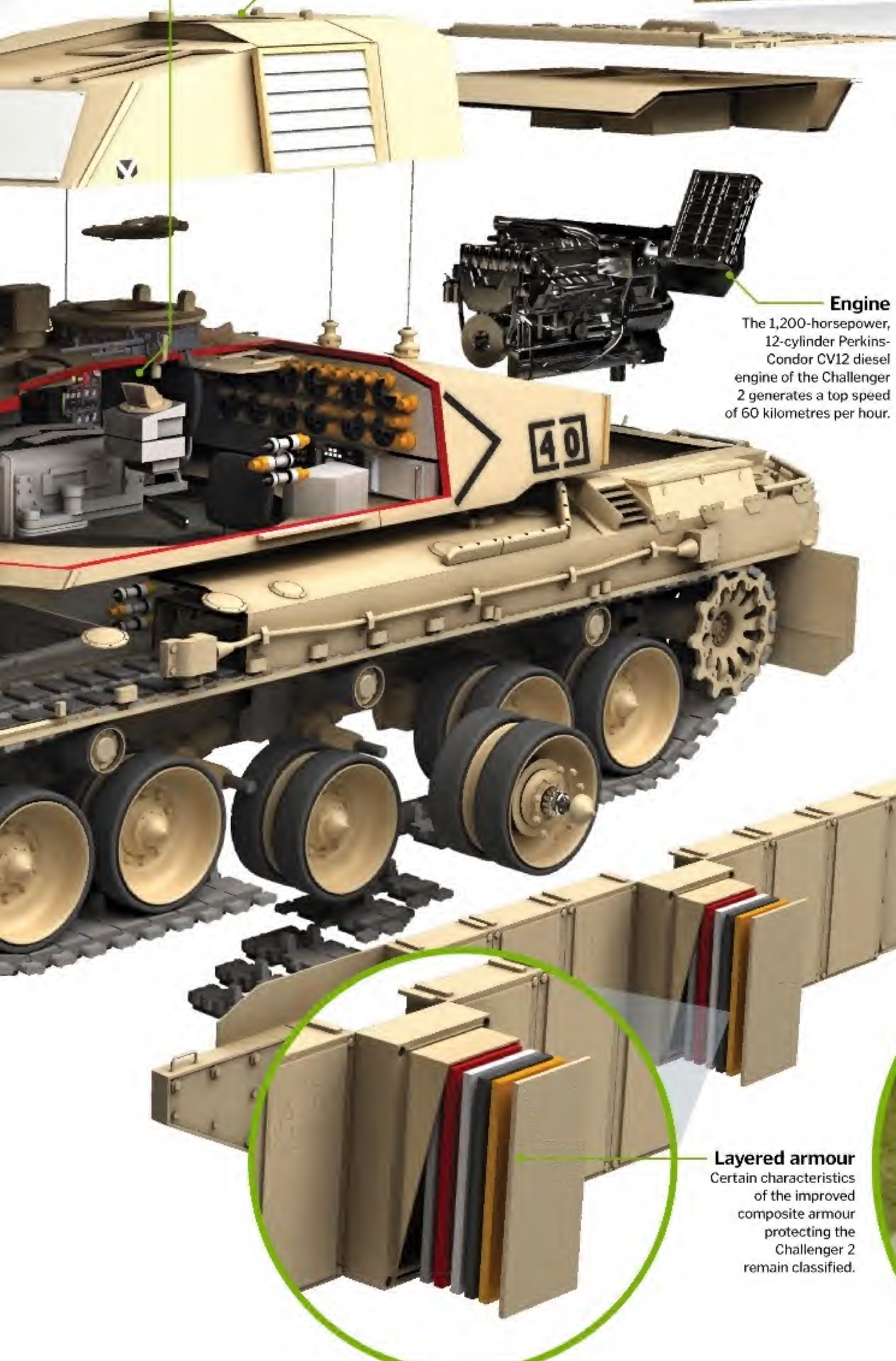
Suspension
A hydro-gas variable spring rate suspension provides stability for the Challenger 2 in cross-country action or on the road.

Tracks
Tension in the Challenger 2's tracks can be hydraulically adjusted from the driver's compartment, to provide excellent mobility on various terrains.

The Japanese Type 90 tank delivers 1,500 horsepower, as much as the Bugatti Chiron, the fastest car in the world

"Technology has transformed the tank into a modern marvel of warfare"

The M1 Abrams has served in the Cold War, Iraq and Afghanistan and is predicted to be in use until 2050



Secondary armament
A pair of 7.62mm machine guns mounted at the loader's hatch provide close defence for the Challenger 2.

Turret
The aerodynamic Challenger 2 turret houses sophisticated vision, target acquisition and defensive systems, along with seating for the commander and the gunner.

Engine
The 1,200-horsepower, 12-cylinder Perkins-Condor CV12 diesel engine of the Challenger 2 generates a top speed of 60 kilometres per hour.

Layered armour
Certain characteristics of the improved composite armour protecting the Challenger 2 remain classified.

In 2007, Canada borrowed 20 Leopard C2 tanks from Germany to aid their troops in Afghanistan

Despite their high-tech defences, modern tanks can still succumb to enemy fire

Challenger 2 entered service with the British Army in 1998

The modern battlefield

From defence to attack, discover the many roles of tanks in warfare

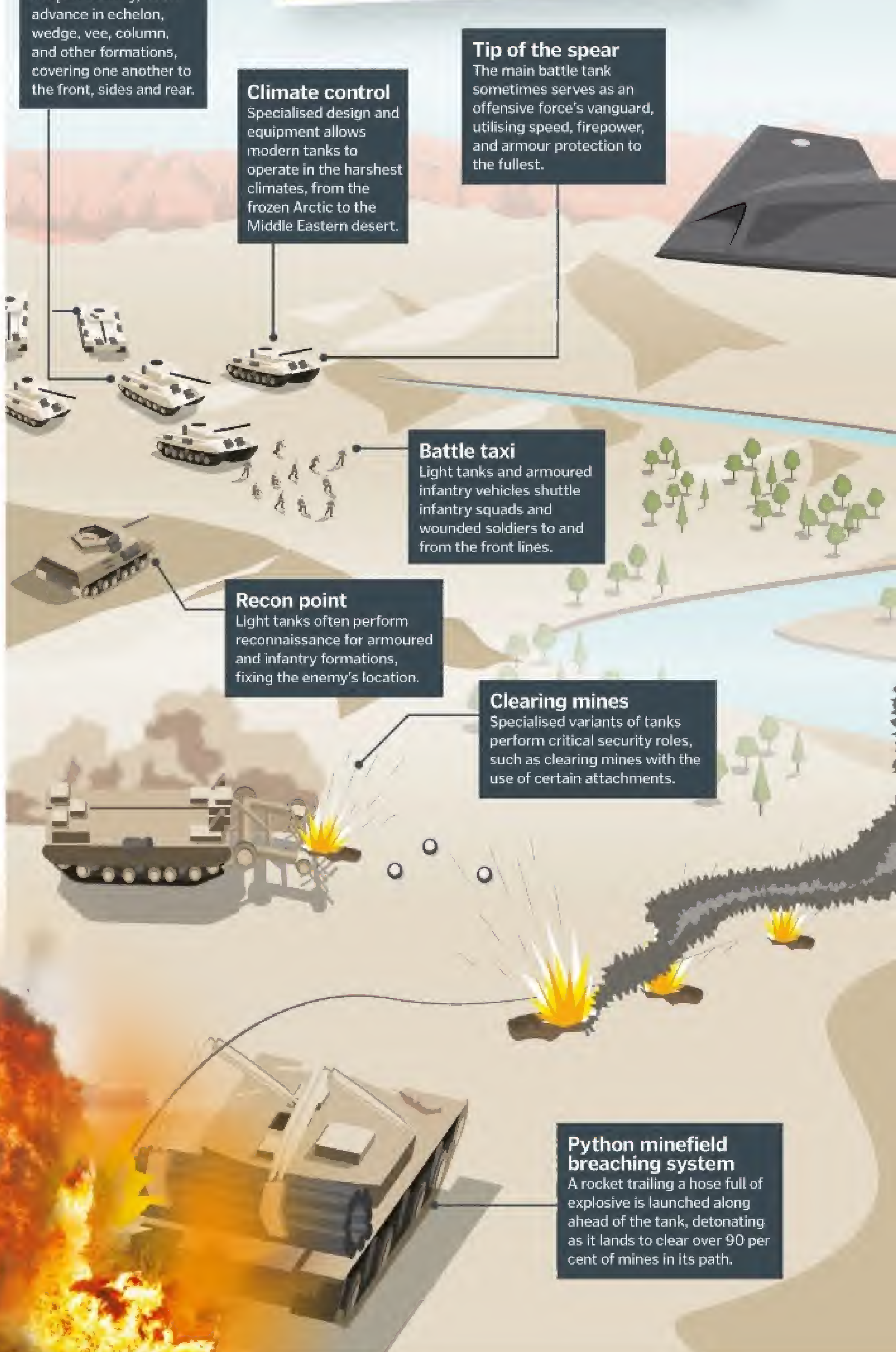
Since their first deployment, tanks have had multiple combat roles. As the world's foremost military organisations began to evaluate the potential of the tank and either embrace or discount its future, military establishments developed their own specific roles for the armoured vehicle.

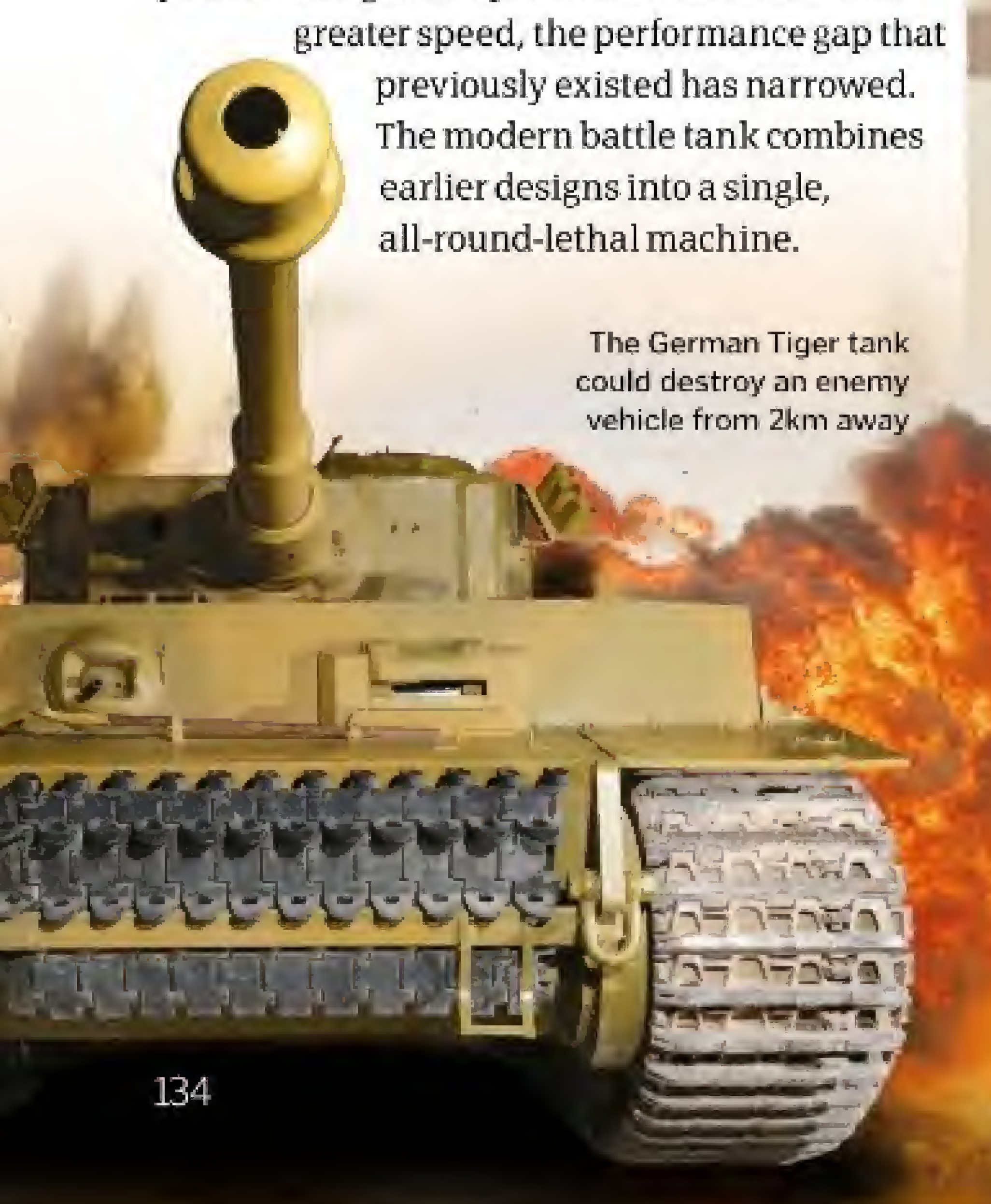
A division of labour emerged. Tanks were either built with heavy armour and weapons for striking power, or slimmed down for speed and rapid manoeuvre. Even during its infancy, the British Tank Corps fielded heavier Mark IV and Mark V tanks in World War I along with the faster and more manoeuvrable Whippet. The heavier tanks were intended to breach German trenches, creating gaps through which the lighter tanks would slash into enemy areas.

While the heavy tanks struck powerful blows, the light tanks served as modern, armoured cavalry. This tactic continued into World War II, with advanced light, medium, and heavy tanks assuming the roles of their predecessors. Tank versus tank combat became more common, and the growing diversity of operational roles resulted in a variety of armoured vehicles, some designed specifically to destroy enemy tanks.

During the Cold War and into the 21st century, cost concerns and improved technology have fuelled the concept of the main battle tank. With highly efficient engines that deliver substantial power and light composite armour that allows greater speed, the performance gap that previously existed has narrowed. The modern battle tank combines earlier designs into a single, all-round-lethal machine.


A Leopard 2A6 of the German Army speeds across flat terrain




The German Tiger tank could destroy an enemy vehicle from 2km away

Tank roles in battle

"Some vehicles were designed specifically to destroy enemy tanks"

Lying hull down in a prepared revetment, this tank can engage the enemy while protected

The British Type 45 has a displacement of 8,000 tons and can carry a crew of around 190

NEXT-GEN BATTLESHIPS

The firepower on the latest battleships is mind-boggling. We explore the technology transforming 21st-century naval warfare

If you thought that the golden age of naval combat came to an end 200 years ago, then clearly somebody forgot to tell the national navies of today. In fact, a wave of state-of-the-art, armed-to-the-teeth battleships are currently emerging from shipbuilding yards with a singular aim in mind: total domination of the seas.

From the brand-new and brutal Type 45 destroyers being pushed out of British dockyards, through to the almost sci-fi Zumwalt-class battleships emerging in the USA, and on to the cruising carrier vessels sitting like small islands in Earth's oceans, battleships are being produced en masse and to a more advanced spec than ever before.

Far from the basic heavyweights of bygone centuries, required simply to go toe-to-toe with each other in a deadly game of broadsides, today's warships need to take down a variety of threats, whether at sea, on land or in the air, and they need to do so at extreme range. As such, step onto a battleship today – be it a frigate, destroyer or corvette – and you'll find an arsenal of insane weapons systems.

There are cannons that can fire over distances of 95 kilometres (60 miles) and deliver a guided smart munition to a target with pinpoint accuracy, as well as Gatling guns that can automatically track a target moving at hundreds of miles per hour and then fire explosive bullets at up to 1,100 metres (3,610 feet) per second to take it down.

Missile launch systems not only increase the vessel's stealth but are capable of launching a wide variety of city block-levelling missiles directly into the heart of enemy encampments in minutes from a safe distance, while naval guns are capable of subjecting a target to continuous bombardment with high-explosive shells with controlled abandon. All this is but a taste of the weaponry being fitted to the most advanced 21st-century warships.

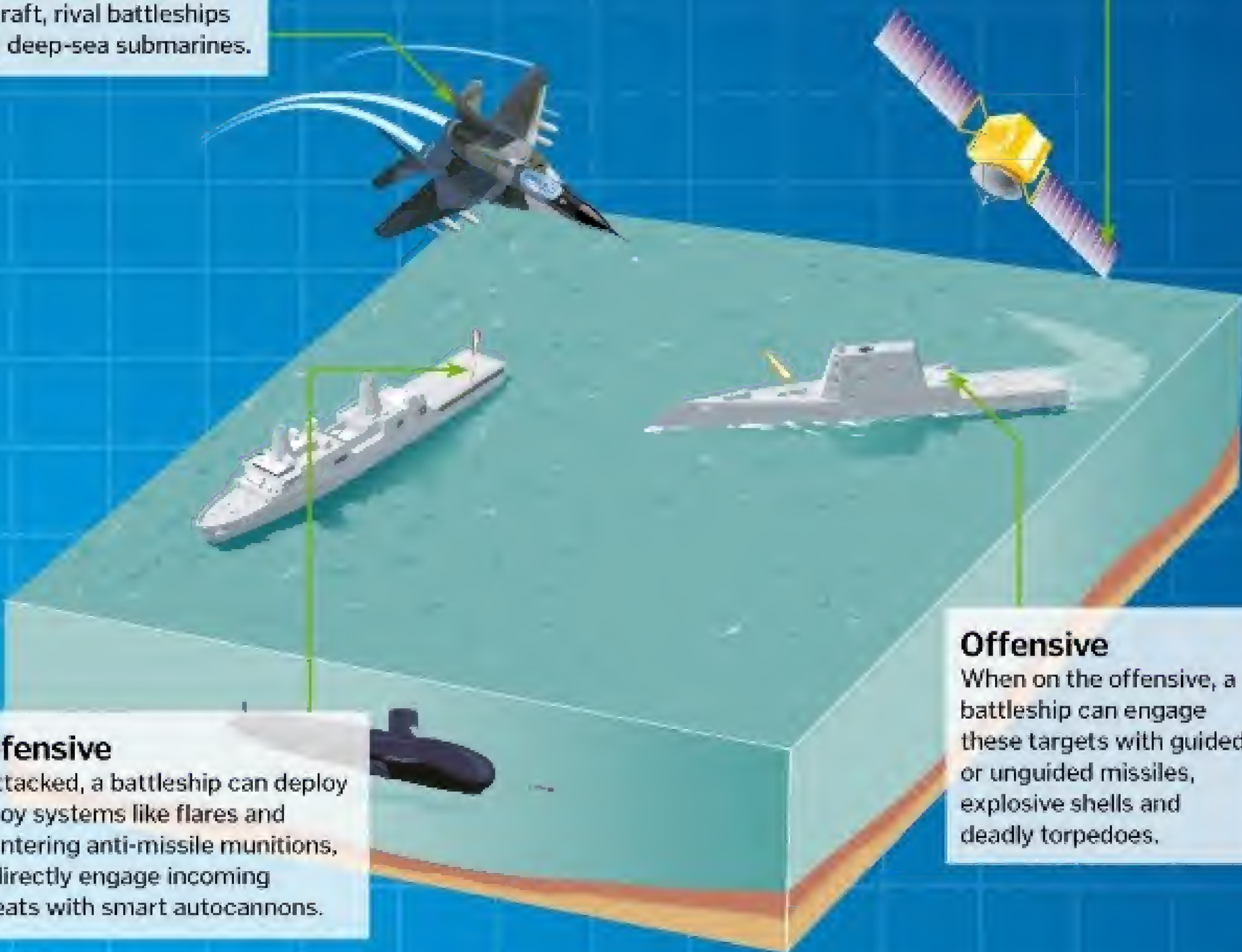
The heavy armament of vessels currently knows no bounds, with even coastguard fleets, convoy vehicles and civilian support ships being outfitted with some form of military-grade offensive weaponry. Clearly, controlling the world's waters is not as old-fashioned as the history books would have us believe. In this feature we take a look at the various types of battleship taking to the seas and the weapon systems that are revolutionising not just naval combat but warfare in general.

Rules of engagement

The key stages and technology that decide the outcome of a modern naval battle

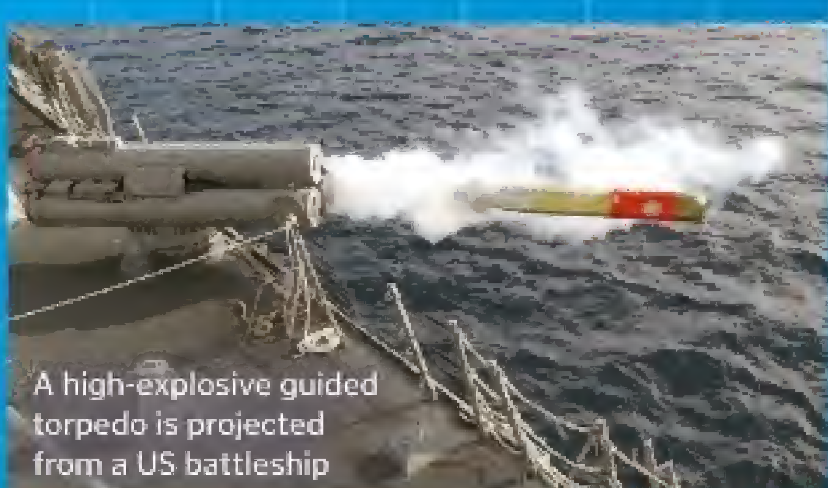
Threats
Modern battleships are designed to engage a number of threats, including high-speed jet aircraft, rival battleships and deep-sea submarines.

Detection
To engage any of these targets first they need to be detected – something achieved via orbiting GPS satellites, radar and sonar communication systems.



Offensive
When on the offensive, a battleship can engage these targets with guided or unguided missiles, explosive shells and deadly torpedoes.

Defensive
If attacked, a battleship can deploy decoy systems like flares and countering anti-missile munitions, or directly engage incoming threats with smart autocannons.



A high-explosive guided torpedo is projected from a US battleship

More traditional 41cm (16in) naval guns on board the USS North Carolina

USS Iowa unloads a volley of explosive shells from its Mark 7 naval guns

Battleship types

1 Corvette
One of the smallest types, the corvette is a lightly armed and manoeuvrable vessel used for coastal operations. Stealth corvettes are now becoming popular too.

2 Frigate
Lightly armed, medium-sized ships generally used to protect other military or civilian vessels. Recently, frigates have been re-focused to take out submarines.

3 Destroyer
Large and heavily armed, destroyers are typically outfitted for anti-submarine, anti-aircraft and anti-surface warfare, and can remain at sea for months on end.

4 Cruiser
The cruiser is an armed-to-the-teeth multi-role vessel akin to a modern destroyer. While cruisers are still in use, they have largely been superseded now.

5 Carrier
Ocean-going leviathans, carriers are the largest battleship. Their primary role is as a seagoing airbase, launching combat aircraft, but they also come heavily armed.

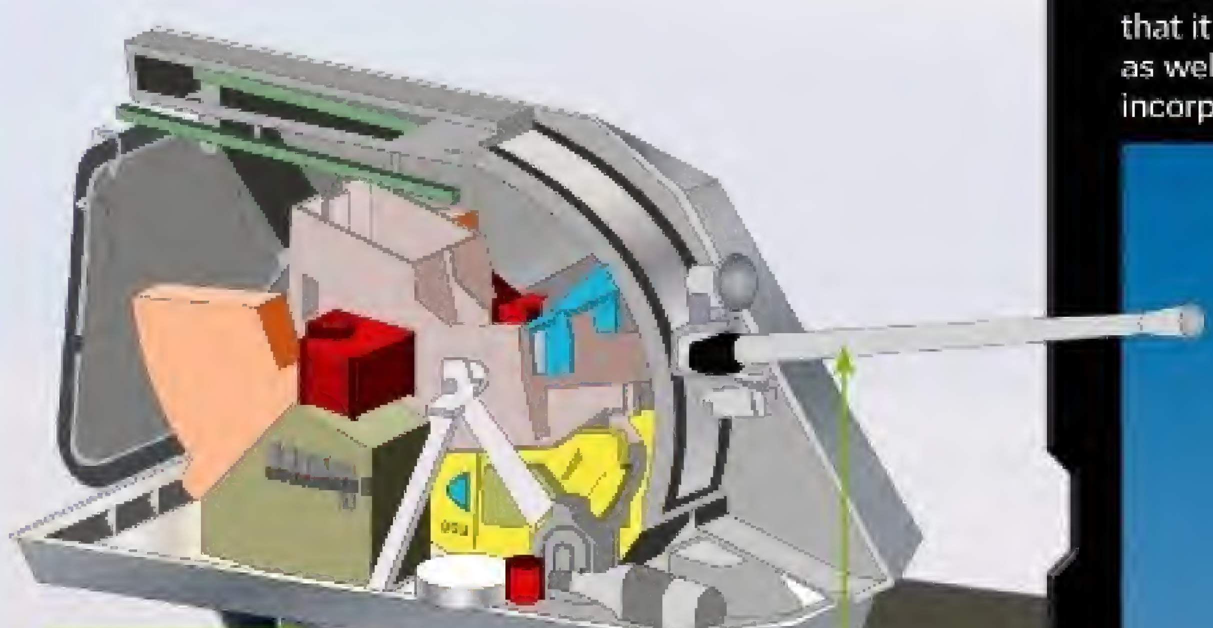
Weapons in focus

We train our sights on four of the most advanced armaments aboard the latest battleships

Mk 110 naval gun

FIRE POWER 3

Capable of delivering automatic salvos of 220 57-millimetre (2.2-inch) Mk 295 Mod 0 ammunition – read: fragmenting high-explosive shells – each and every minute, the Mk 110 naval gun is quite simply a shell-slinging colossus. Stemming from one of the most long-lasting naval gun series of the last 100 years, the Mk 110 comes with a selection of hot features. These include the ability to fire both standard and smart munitions, a gun barrel-mounted radar for refined measuring of muzzle velocity, an instantaneous ability to switch between ammunition types, a stealth-oriented ballistic shield that protects the gun while allowing a full 360-degree traverse, plus a fully digital fire control system that enables the Mk 110 to respond to exact pointing orders and ammunition fuse selection milliseconds prior to firing. Indeed, the only thing that stops the Mk 110 from bombarding its target continuously is its shell capacity, which rests at 120 rounds with a three-minute reload process.



Turret
The MK 110's turret is capable of a full-circle sweep and contains the gun's firing systems. The turret allows the gun to elevate from -10° through to +77° and is protected with a ballistic shield to disguise it from radars.

Barrel
The MK 110 has a single firing barrel with a progressive, 24-groove parabolic twist. The barrel's bore length is 3,990mm (157in), with the gun capable of firing 57mm (2.2in) conventional and smart munitions.

Hoist
The MK 110's 57mm (2.2in) Mk 295 Mod 0 ammunition is delivered to the turret emplacement via a mechanical loading hoist. Ammunition is stacked 120 rounds deep and automatically fed into the firing chamber.

Advanced Gun System

FIRE POWER 4

The Advanced Gun System (AGS) is a new naval gun from BAE Systems capable of firing precision munitions super-fast and at over-the-horizon ranges. What makes it special is that far from firing traditional unguided shells – as most naval guns have been designed for – it fires the Long Range Land Attack Projectile (LRLAP), a 155-millimetre (6.1-inch) precision guided artillery shell that, thanks to base bleed rocket assistance and an extended range fin glide trajectory, can travel over 105 kilometres (65 miles) to a target. What's more, it then has a circular error probable (ie accuracy) of only 50 metres (164 feet), making it incredibly precise even at great distance. Throw in the fact that the AGS can fire ten of these LRLAPs per minute from its stealth-designed turret and that it can fire traditional unguided munitions as well and it becomes clear why it's being incorporated into many of today's warships.

Vertical Launch System

FIRE POWER 5

The Vertical Launch System (VLS) is a state-of-the-art multi-missile launching system. Unlike previous systems, which could only fire one specific type of missile, the VLS is modular so a variety of projectiles can be fired from the same enclosures. The missiles, which on the Zumwalt-class destroyers include the RIM-162 Evolved Seasparrow missile, Anti-Submarine Rocket (ASROC) and Tactical Tomahawk subsonic cruise missile, are enclosed in a series of launch cells within the ship's hull and, when launched, are fired out of the top of the deck. By concealing the missiles within the ship until needed, the VLS improves the ship's overall radar cross-section, making it harder to detect. Each missile fired from a VLS cell is of the guided variety, with a selection of high-explosive warheads directed to the target by radar or GPS.

Phalanx CIWS

FIRE POWER 3

Every battleship built today comes with a close-in weapon system, or CIWS, and out of these systems the Phalanx CIWS is the leader of the pack. It is a point-defence weapon designed to attack any target – be that enemy fighter jets or missiles – which has managed to evade the battleship's longer-range offensive weapons with its massive 20mm (0.8in) M61 Vulcan Gatling gun. What makes it really special though is its advanced targeting system, which consists of two independent antennas that work together to engage a target. The first antenna is used for searching for the incoming target and delivers bearing, velocity, range and altitude information. The second antenna is then used to track the target on its approach until it is in firing range. As soon as an incoming target is close enough, the Phalanx can then automatically fire, using a selection of sensors to guide spent rounds at the unfortunate target in a split second.

Radar
A bulbous tubular radome encases the Phalanx's Ku-band search and gun-laying radar. The search antenna sweeps for threats, and once a target is confirmed as hostile, the gun-laying antenna locks on.

Drum
Ammunition for the Gatling cannon comes courtesy of a large magazine drum. This dispenser can feed the cannon at a rate of over 4,000 rounds per minute.

Gun
Damage is dealt with a 20mm (0.8in) M61 Vulcan autocannon. The cannon has a muzzle velocity of over 1,100m/s (3,600ft/s) and an effective range of up to 3.6km (2.2mi).

HOW IT WORKS

HISTORIC

Iconic machines that changed the world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"The Mayflower was often regarded as a symbol of religious freedom in the United states"

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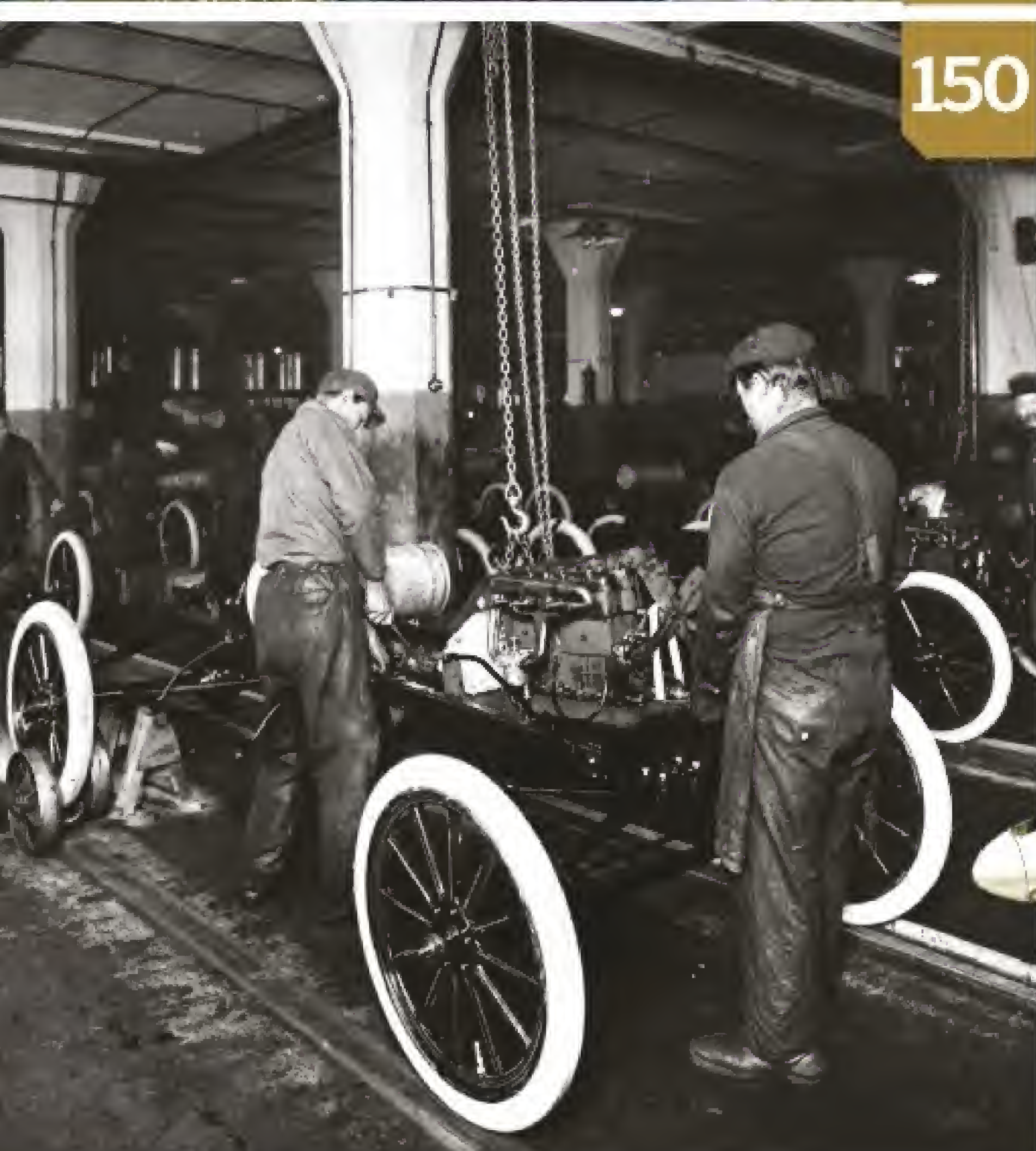

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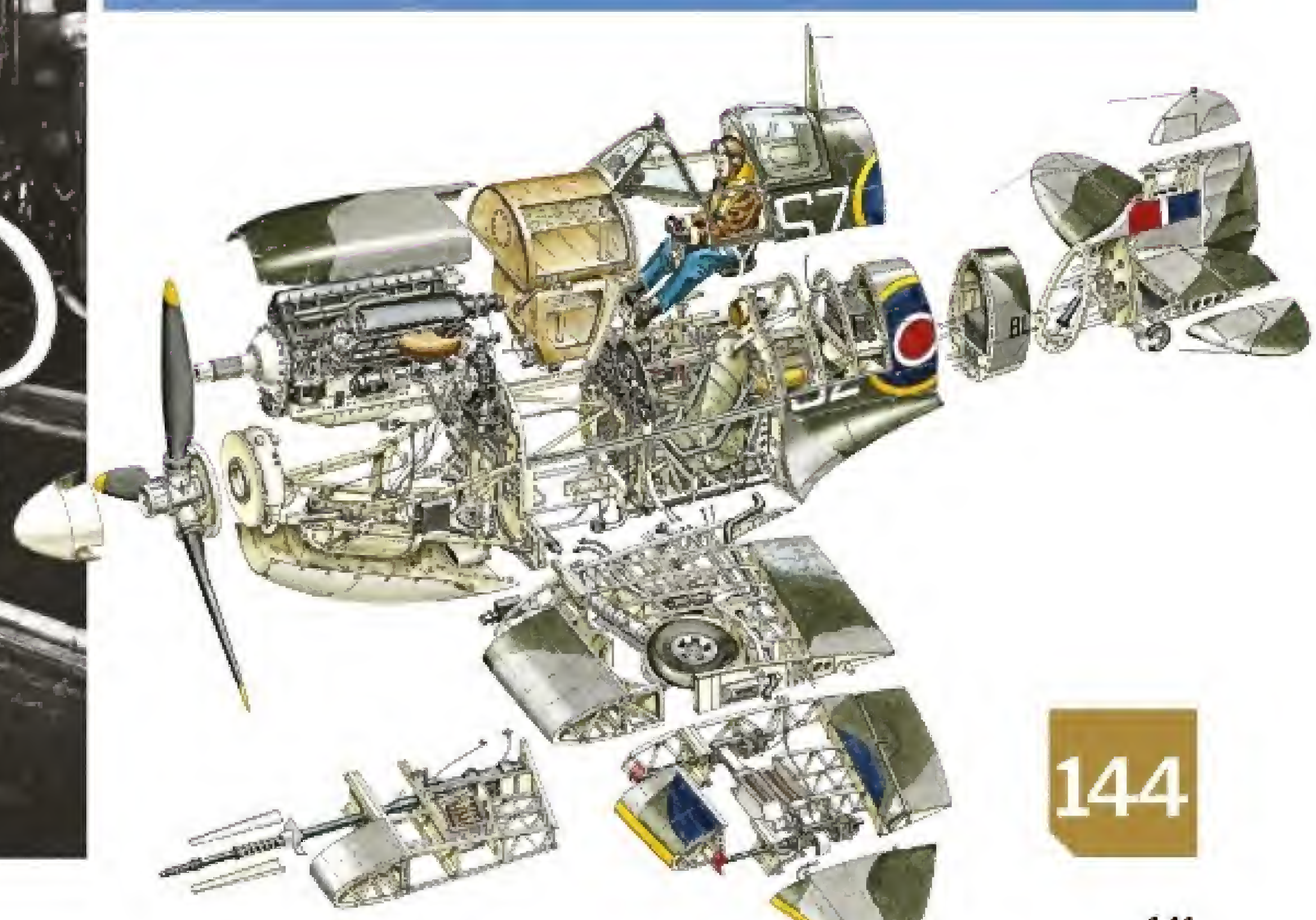

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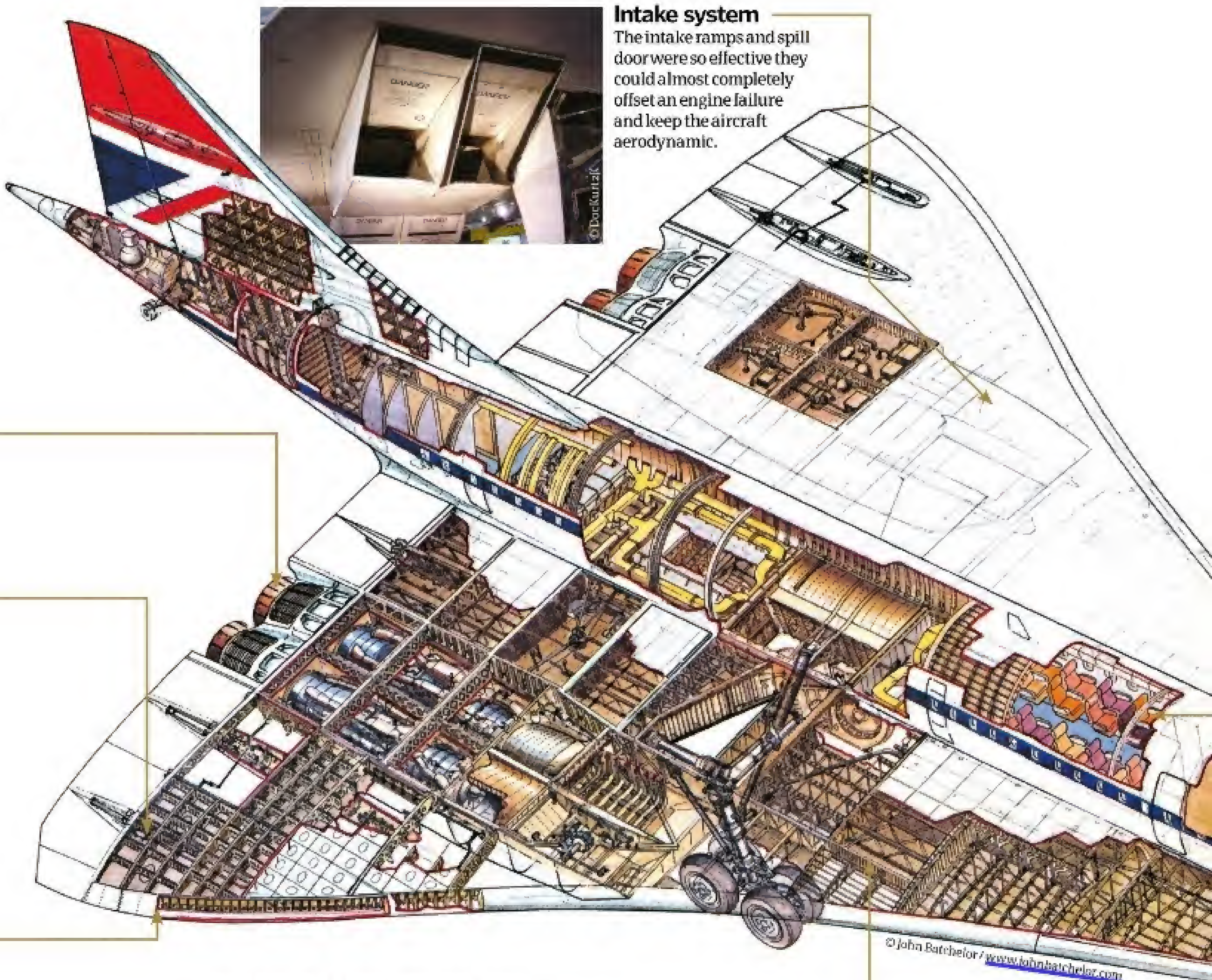
Inside Concorde

What's under the wings?



Intake system
The intake ramps and spill door were so effective they could almost completely offset an engine failure and keep the aircraft aerodynamic.

Rolls-Royce/Snecma Olympus 593 engines
Concorde's afterburning engines were a development of engines originally designed for the Avro Vulcan bomber.

Wing fuel tanks
Concorde, like many aircraft, stored its fuel in its wings. However, it also used its fuel as a heat sink, drawing heat away from the passengers.

Ogival wings
Concorde's 'double delta' wings helped its aerodynamic profile and speed.

Lighter, stronger components
Concorde was constructed using 'sculpture milling', a process that reduced the amount of parts required while making those that were necessary lighter and stronger.

Concorde

An aircraft that could fly across the Atlantic in under three hours seemed as impossible as it was desirable

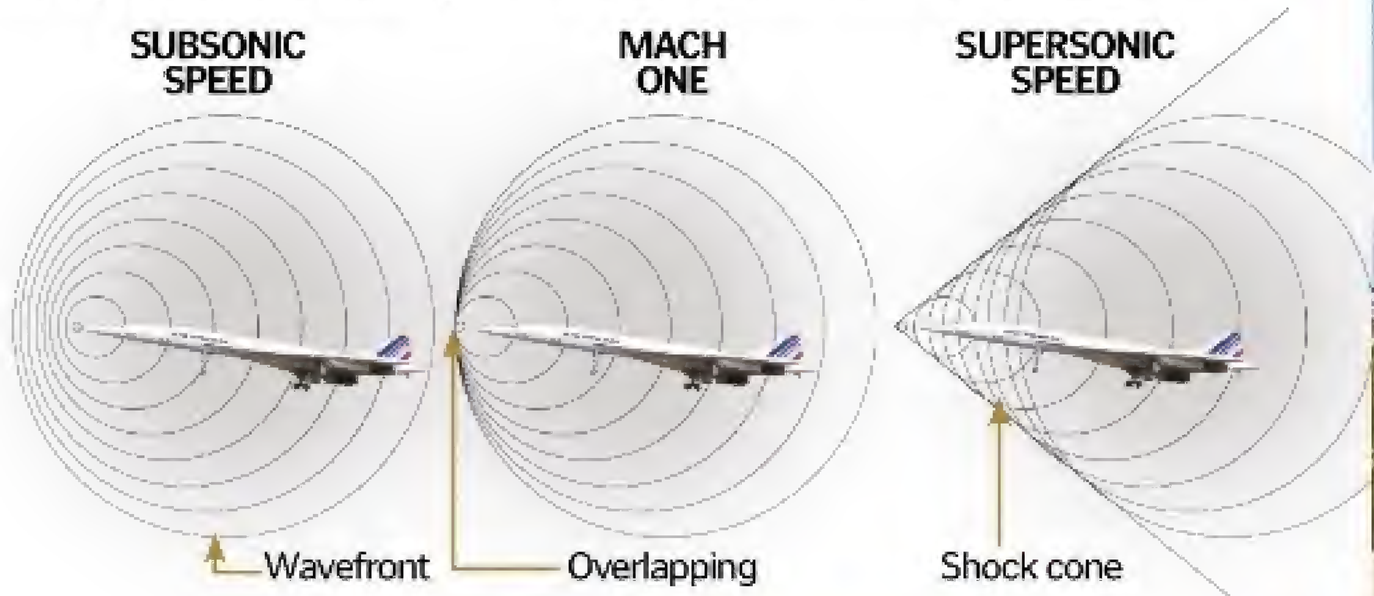
Flying faster than the speed of sound has always been the sole proviso of the military, but in the late-Sixties, Russia, France, the UK and the US were all working on the idea of supersonic commercial travel.

Concorde was the result of France and the UK combining their efforts to produce a supersonic airliner and, even now, it's impossible not to be impressed by its pioneering stature. Its ogival or double-curved wings kept it aerodynamic and dictated much of the plane's shape, as they forced the nose up on taxiing, take off and landing. To help minimise drag on the aircraft as well as improve visibility, the nose cone could move, dropping down to improve visibility then straightening out in flight to improve the aerodynamic profile.

Concorde's engines also had to be modified for extended supersonic flight. Jet engines can only take in air at subsonic speed so the air passing into the engines had to be slowed when flying at Mach 2.0. Worse, the act of slowing the air down generated potentially damaging shock waves. This was controlled by a pair of intake ramps and an auxiliary spill door that could be moved during flight, slowing the air flow then and allowing the engine to operate efficiently. This system was so successful that 63 per cent of Concorde's thrust was generated by these intakes during its supersonic flight.

The sonic boom

Sonic booms are generated by the passage of an object through the air. This passage creates pressure waves that travel at the speed of sound. The closer the aircraft gets to the speed of sound, the closer these waves become until they merge. The aircraft then forms the tip of a 'Mach cone', the pressure wave at its nose combining with the fall in pressure at its tail as it passes to create the distinctive 'boom' sound.



This Concorde is on display at Paris-Charles de Gaulle airport

End of an era

On 25 July 2000, Air France Flight 4590 crashed in Gonesse, France, killing all 100 passengers and nine crew as well as a further four on the ground.

Although the crash was caused by a fragment from the previous aircraft to take off, passenger numbers never recovered and were damaged still further by the rising cost of maintaining the ageing aircraft and the slump in air travel following the 9/11 attacks.

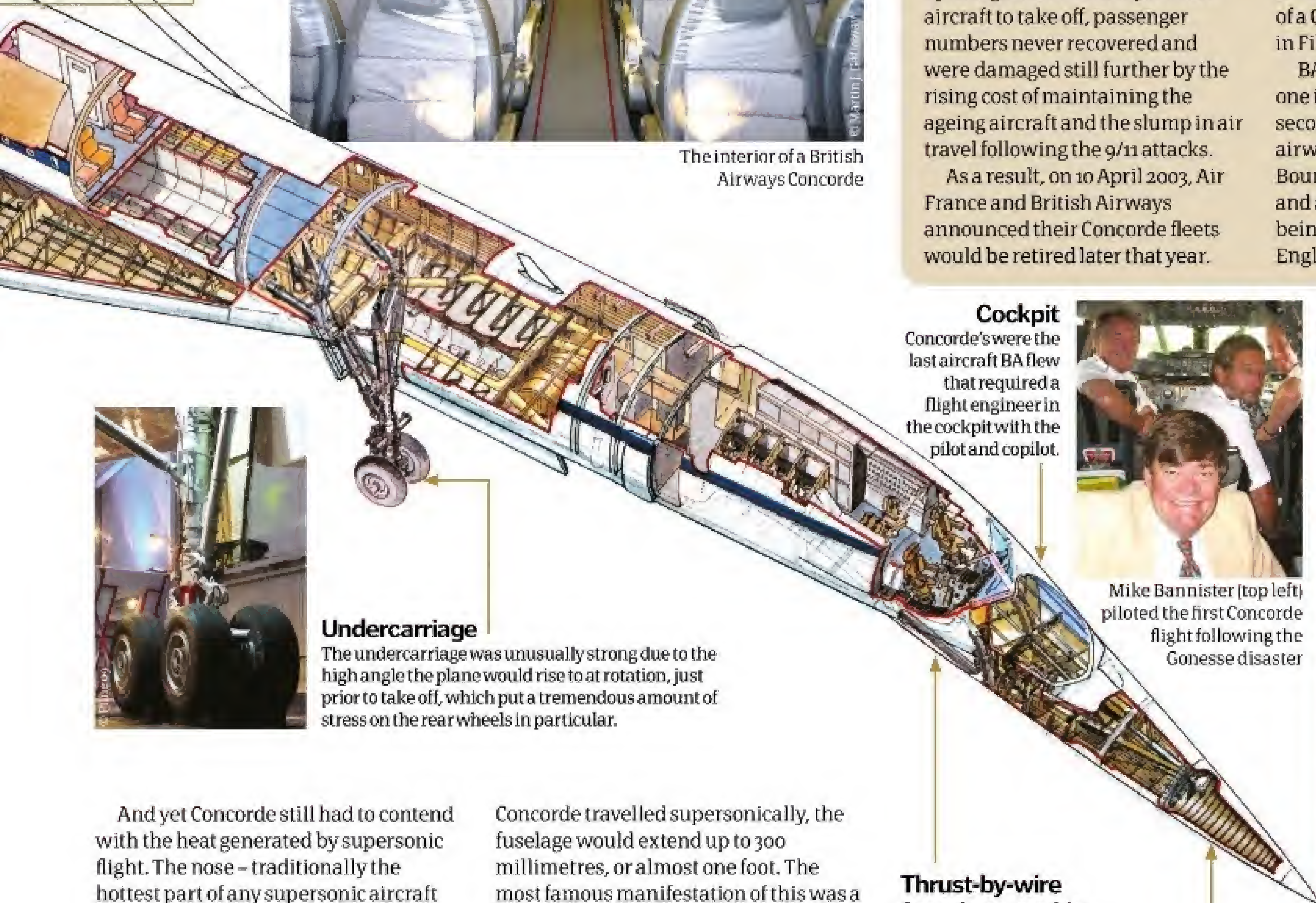
As a result, on 10 April 2003, Air France and British Airways announced their Concorde fleets would be retired later that year.

Despite an attempt by Richard Branson to purchase BA's Concorde fleet for Virgin Atlantic, the planes were retired following a week-long farewell tour that culminated in three Concordes landing at Heathrow, and the very final flight of a Concorde worldwide landing in Filton, Bristol.

BA still owns its Concorde fleet: one is on display in Surrey, a second is being kept near-airworthy by volunteers at the Le Bourget Air and Space Museum, and a third, also at that site, is being worked on by a joint team of English and French engineers.

The interior of a British Airways Concorde

Passenger cabin
Concorde could carry 92 passengers or be reconfigured internally to carry up to 120.



Undercarriage
The undercarriage was unusually strong due to the high angle the plane would rise to at rotation, just prior to take off, which put a tremendous amount of stress on the rear wheels in particular.

Cockpit
Concorde's were the last aircraft BA flew that required a flight engineer in the cockpit with the pilot and copilot.

Mike Bannister (top left) piloted the first Concorde flight following the Gonesse disaster

Thrust-by-wire
Concorde was one of the first aircraft to use an onboard computer to help manage its thrust levels.

Nose
Concorde's nose drooped to help visibility on take off and landing and straightened in flight.

And yet Concorde still had to contend with the heat generated by supersonic flight. The nose – traditionally the hottest part of any supersonic aircraft – was fitted with a visor to prevent the heat reaching the cockpit while the plane's fuel was used as a heat sink, drawing heat away from the cabin.

Even then, owing to the incredible heat generated by compression of air as Concorde travelled supersonically, the fuselage would extend up to 300 millimetres, or almost one foot. The most famous manifestation of this was a gap that would open up on the flight deck between the flight engineer's console and the bulkhead. Traditionally, engineers would place their hats in this gap, trapping them there after it closed.

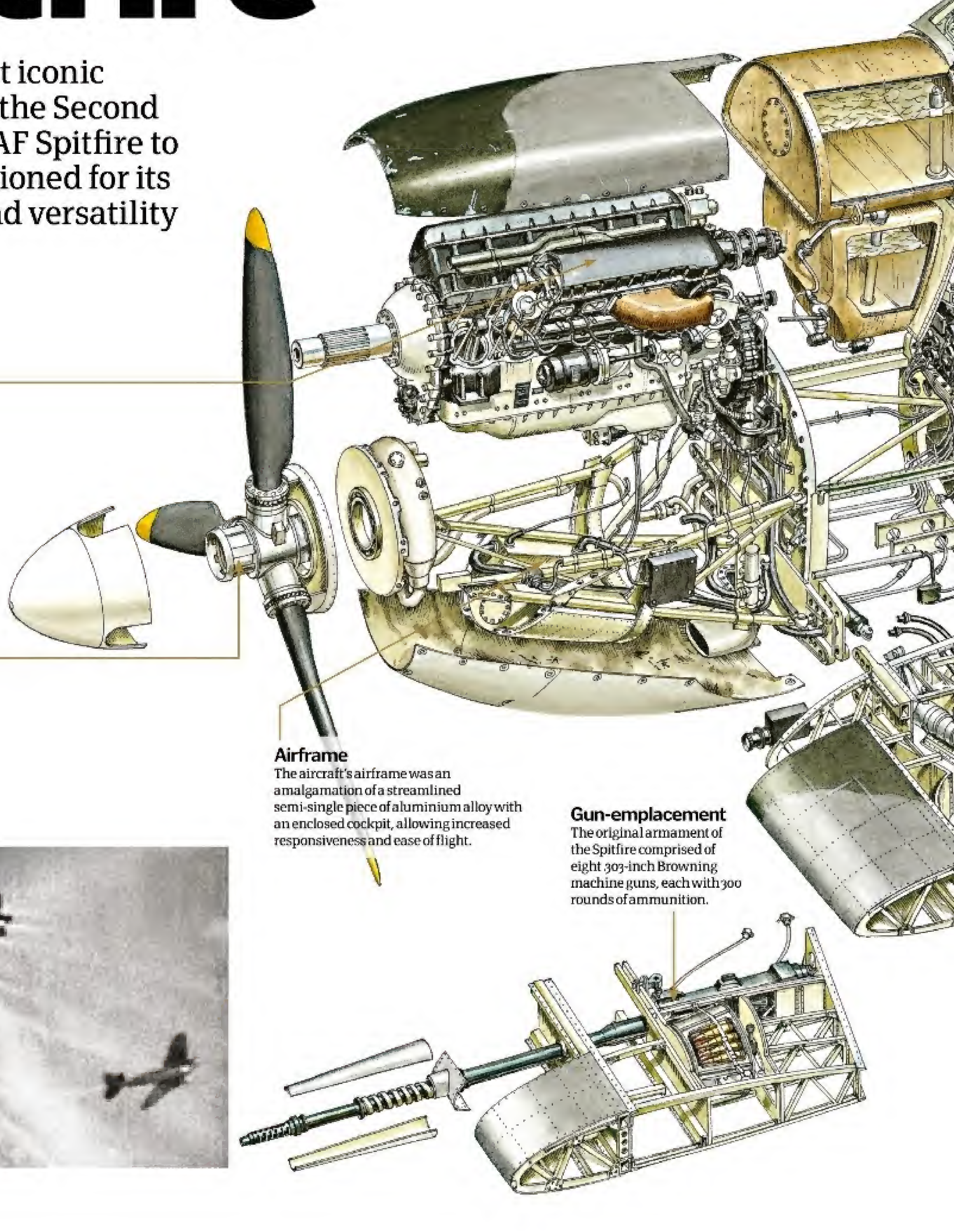
The statistics...

BAC/Aerospatiale Concorde

Manufacturer: BAC (Now BAE Systems) and Aerospatiale (Now EADS)
Year launched: 1976
Year retired: 2003
Number built: 20
Dimensions: Length: 61.66m
Wingspan: 25.6m
Height: 3.39m
Capacity (passengers): Up to 120 passengers
Unit cost: £23 million in 1977
Cruise speed: Mach 2.02 (1,320mph)
Max speed: Mach 2.04 (1,350mph)
Propulsion: 4x Rolls-Royce/Snecma Olympus 593 engines
Ceiling: 60,000ft

Supermarine Spitfire

Arguably the most iconic fighter aircraft of the Second World War, the RAF Spitfire to this day is championed for its prowess, grace and versatility



Rolls-Royce Vee-12 engine
The Spitfire utilised two variant of Rolls-Royce engine during its production life span, the 27-litre Merlin and the 36.7-litre Griffon.

Propeller
Original Spitfires had wooden propellers, these were later replaced with variable-pitch propellers, and more blades were added as horsepower increased.

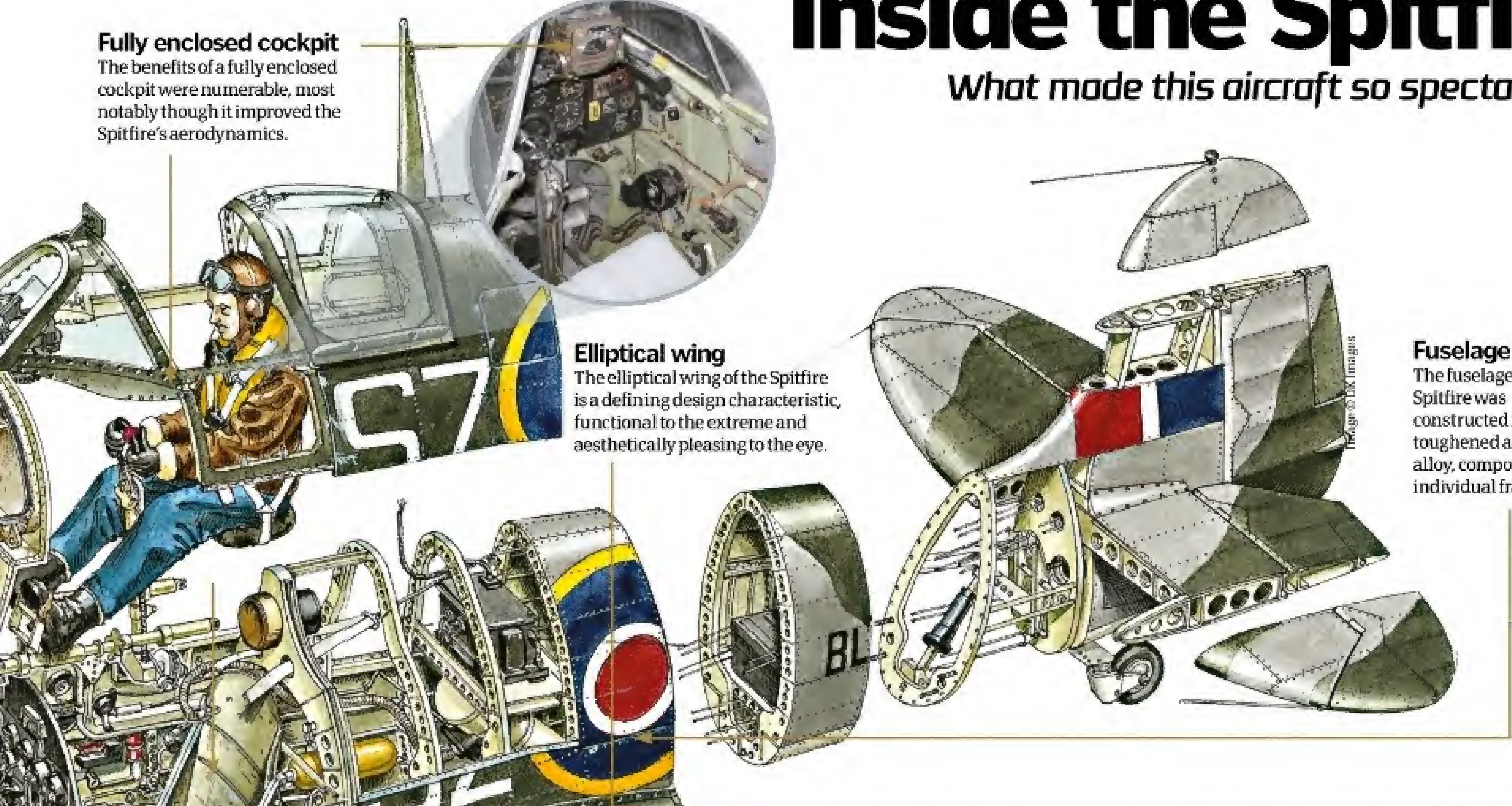
Airframe
The aircraft's airframe was an amalgamation of a streamlined semi-single piece of aluminium alloy with an enclosed cockpit, allowing increased responsiveness and ease of flight.

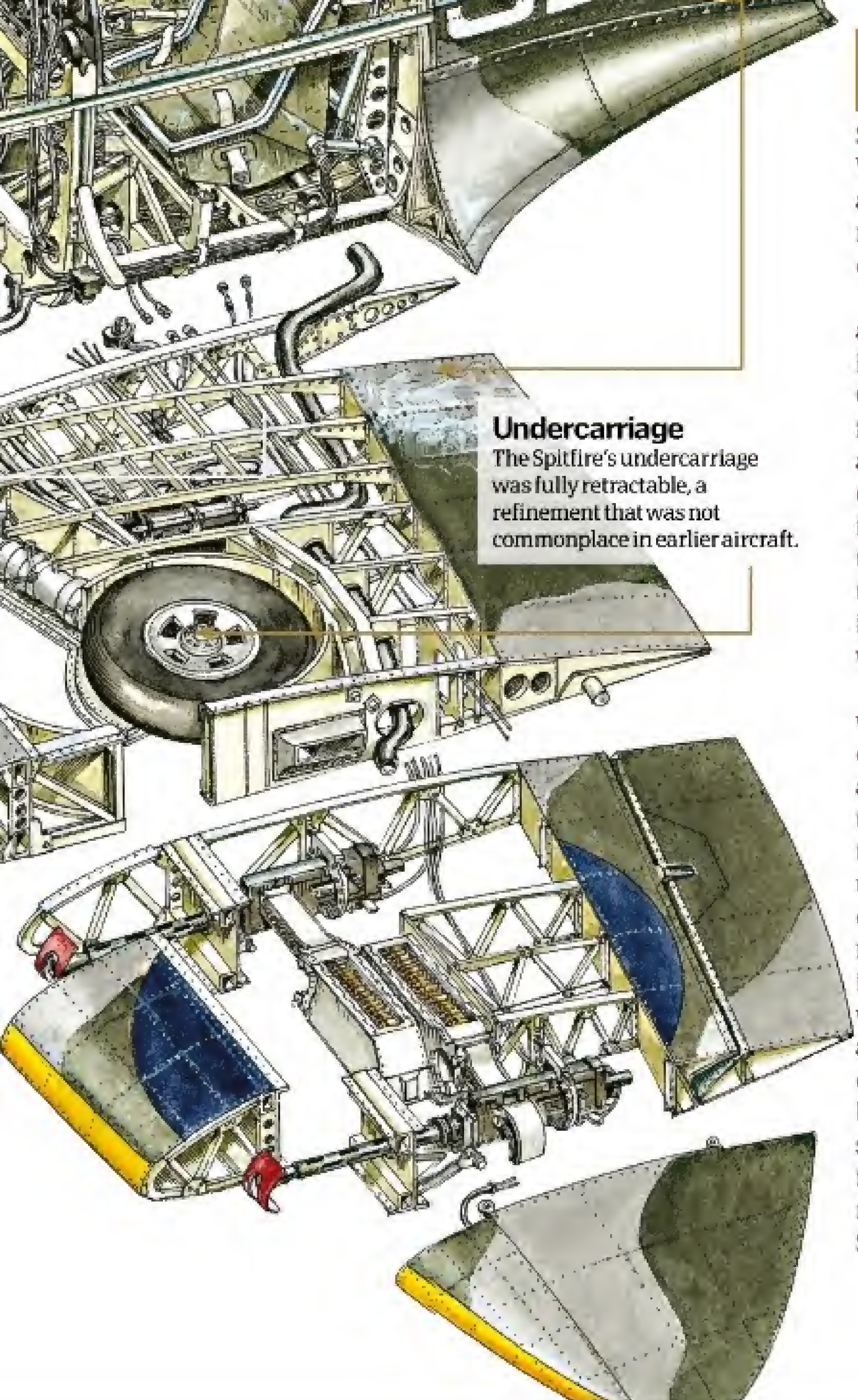
Gun-emplacement
The original armament of the Spitfire comprised of eight .303-inch Browning machine guns, each with 300 rounds of ammunition.

Video still from gun camera showing the tracers

Inside the Spitfire

What made this aircraft so spectacular?





Designed in the technologically fervent and innovatory melting pot of the Second World War, the Supermarine Spitfire became the fighter plane of the times. With its simple lines, elegant frame and superb aerodynamics, the Spitfire was to live on in the minds of generations during the war and for decades to come.

The Spitfire was the brainchild of aeronautical engineer Reginald Mitchell, who led a dedicated and talented team of designers. Originally planned as a short-range air-defence fighter, the Spitfire was built for speed and agility, traits that it was to need in the explosive dogfights it was to partake in as it met enemy fighters and bombers. Building a fighter plane, though, is more complex than listing desirable traits however, and the Spitfire's construction is a balletic series of compromises between weight, aerodynamics and firepower.

The frame of a spitfire with its elliptical wings is one of its most defining characteristics, casting a distinctive silhouette against the sky. The ellipse shaping was used to minimise drag while having the necessary thickness to accommodate the retracted undercarriages and the guns required for self defence. A simple compromise that had the resulting benefit of having an incredibly individual shape. In contrast, the airframe – which was influenced by exciting new advances in all metal, low-wing plane construction – was a complex and well-balanced amalgamation of a streamlined semi-single piece of aluminium alloy and a fully enclosed cockpit. This allowed unrivalled responsiveness and ease of flight, making the Spitfire a favourite for pilots.

Arguably, the other most defining and success-inducing element of the Spitfire was its engine, which took on the form of the Rolls-Royce Merlin and Griffon engines. Planned by a board of directors at Rolls-Royce who realised that their current Vee-12 engine was topping out at 700hp and that a more powerful variant would be needed, first the Merlin and later the Griffon engines were designed. The Merlin at first delivered 790hp, short of the 1,000hp goal set in its design brief, however this was to increase to 975hp in a few years. The Griffon then built upon the success of the Merlin, delivering at the climax of its advancement a whopping 2,035hp. These engines were to prove tantamount to the airframe and wing designs in the dominance of the Spitfire.

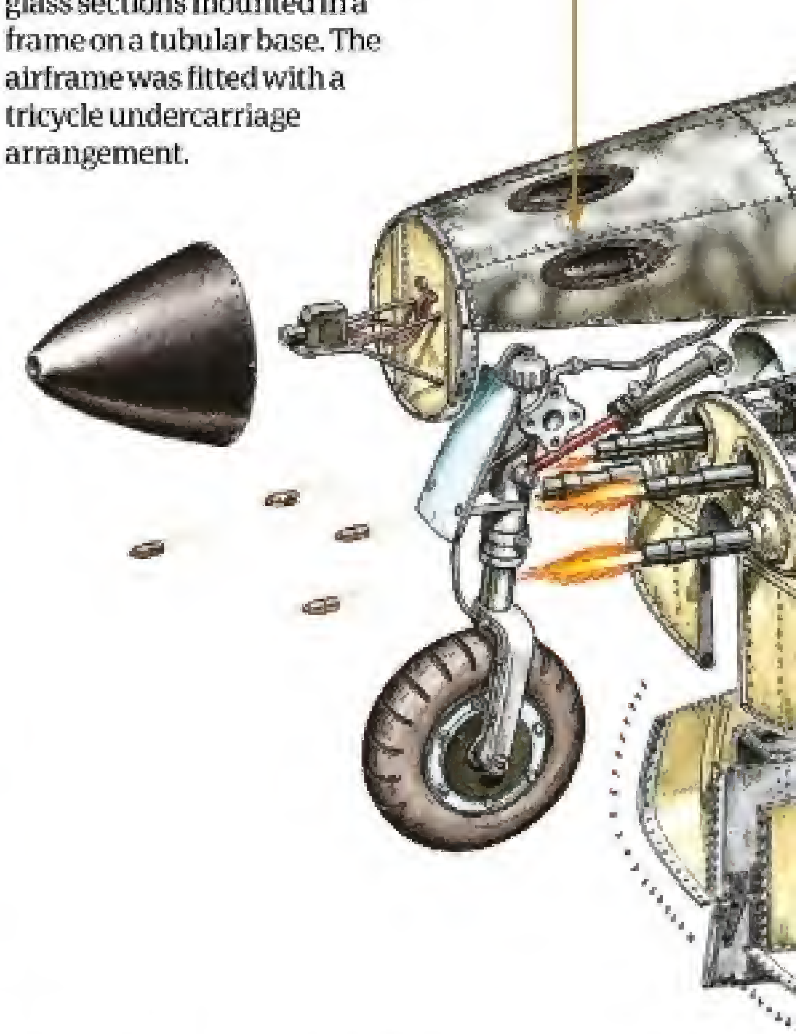
Despite its origins lying in short-range home defence, the Spitfire was to prove so versatile and successful that it was quickly adapted for a wide variety of military purposes. Many variants were created, including designs tailored for reconnaissance, bombing runs, high-altitude interception and general fighter-bomber operations. The most notable derivative, however, was the multi-variant Seafire, specially designed for operation on aircraft carriers with the added ability to double-fold its wings for ease of storage.

Considering the place in history that the Spitfire holds – a fighter-bomber aircraft that bridged the gap between the age of the propeller engine to that of the jet – the fact that they are still collected (with an average cost of £1.4 million) and flown today is unsurprising. The Spitfire is a timeless piece of engineering that shows some of the most creative and advanced efforts in military history.

Messerschmitt Me 262

How this German fighter aircraft brought terrifying speed and combative dominance to the aerial battlefields of World War II


The Messerschmitt Me 262 Schwalbe, as seen in this photograph, was the first variant of the jet to fall into Allied hands



Speed kills. This is a fact of war that the Nazi regime understood well, employing it to great effect with their 'Blitzkrieg' (lightning war) tactics of WWII, puncturing holes in Allied lines with great speed and firepower. It was a mantra they incorporated into all aspects of their military and, as shown in the groundbreaking Messerschmitt Me 262 fighter jet, often generated spectacular results.

The Me 262 was the most advanced aviation design brought to fruition during World War II, and the first ever operational jet-powered fighter aircraft in the world. It featured a state-of-the-art, streamlined steel and aluminium alloy chassis, twin super-powerful Junkers Jumo 004 B-1 turbojet engines and a suite of weaponry that allowed it to fulfil a wide variety of roles. It was originally conceived to be a high-speed fighter-interceptor used to take down Allied bombers during sorties (flight missions), however under order from Adolf Hitler himself, its role was widened to also include bombing duties.

Its aerial dominance rested on its high top speed of 900km/h (560 mph), which obliterated its nearest rivals, the American P-51 Mustang and British Spitfire. Indeed, the extreme velocity that the Me 262 brought to the aerial battlefield meant that traditional dog-fighting tactics needed to be rewritten, with Allied pilots unable to track the aircraft with their electric gun turrets or tail them over long stretches. Instead, Allied pilots had to gang up and attempt to force the 262's pilot into making low-speed manoeuvres, from which it could be shot down.

This formidable power came from the turbojets. They didn't provide as much thrust at lower speeds than that of propellers, meaning that Me 262s took longer to reach high speed. However, once flying, the aircraft could easily outpace any Allied plane. Further, the turbojets granted the Me 262 a higher rate of climb than its contemporaries, which, when used tactically, allowed them to out-position the enemy and line up attack runs on lower-flying bombers. Air-to-air damage was delivered with four 30mm MK 108 cannons, as well as 24 55mm R4M rockets. The Me 262's cannons allowed for short-range firing runs, while the unguided R4M rockets allowed larger targets to be peppered with high-explosive munitions, each one capable of totally destroying any aircraft of the day. Air-to-ground attacks were actualised through a selection of 250kg or 500kg (550lb to 1,100lb) free-fall bombs, which were stored and released from dedicated bomb bays. Through its weaponry and intense speed, the Me 262 racked up a reported five-to-one kill rate, shooting down a variety of different Allied aircraft.

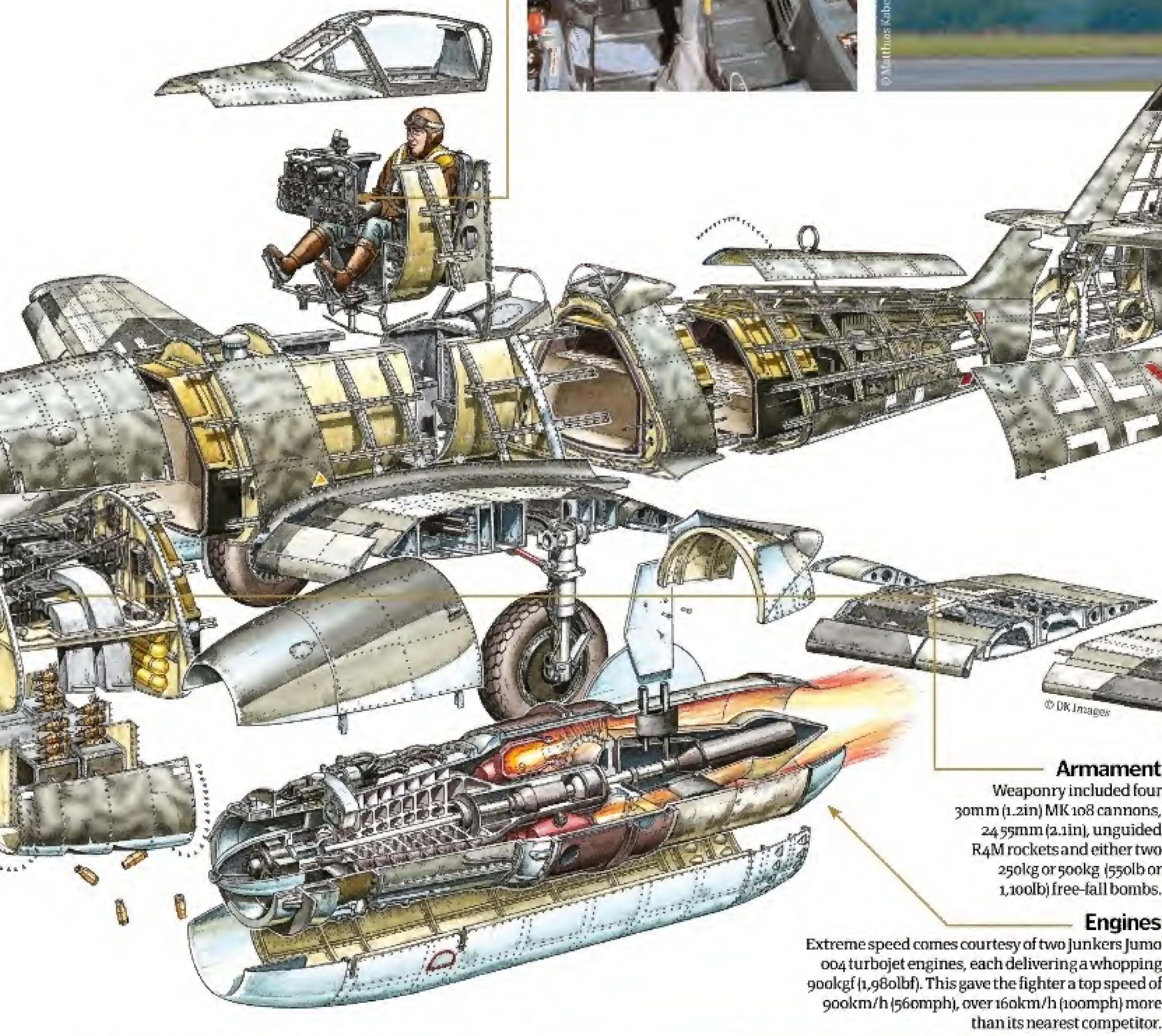
Unfortunately, the reign of the Me 262 was short-lived, as mass delays in bringing it to operational functionality meant that it was not introduced until the spring of 1944, just over a year before the close of the war. Poor parts availability and dissemination of maintenance information to mechanics led to serious deficiencies in fleet fly time,

The Me 262's engines allowed a top speed of 900km/h

© Matthias Kabel

Instrumentation

Flight instruments in the Me 262's cockpit included an artificial horizon, bank and turn indicators, airspeed indicator, altimeter, rate of climb indicator, repeater compass and blind approach indicator.



© DK Images

Wings

The Me 262 sported a swept-wing profile, with a leading edge sweep of 18.5°. This sweep was added to the aircraft – the original design did not feature swept wings – as the Jumo 004 engines proved heavier than expected and the centre of lift needed to be repositioned.

Armament

Weaponry included four 30mm (1.2in) MK 108 cannons, 24 55mm (2.1in), unguided R4M rockets and either two 250kg or 500kg (550lb or 1,100lb) free-fall bombs.

Engines

Extreme speed comes courtesy of two Junkers Jumo 004 turbojet engines, each delivering a whopping 900kgf (1,980lbf). This gave the fighter a top speed of 900km/h (560mph), over 160km/h (100mph) more than its nearest competitor.

with few aircraft in the air at any one time. Due to its aerial dominance, Allied forces identified the Me 262's potential threat and dedicated large quantities of bombing sorties to destroying construction factories and launch bases.

> *"The Me 262 was the most advanced aviation design brought to fruition during World War II"*

The statistics...

Me 262 A-1a

Crew: 1

Length: 10.6m (34.8ft)

Wingspan: 12.6m (41.5ft)

Height: 3.5m (11.5ft)

Weight: 3,795kg (8,367lb)

Powerplant: 2 x Junkers Jumo 004 B-1 turbojet engines (1,980lbf each)

Max speed: 900km/h (559mph)

Range: 1,050km (652mi)

Max altitude: 11,450m (37,566ft)

Armament: 4 x 30mm MK 108 cannons, 24 x 55mm R4M rockets, 2 x 250kg bombs

F-86 Sabre

Considered the foremost military aircraft of the Fifties, the F-86 Sabre was a highly versatile fighter jet as fast as it was lethal

The F-86 Sabre was a highly successful single-seat fighter jet built by North American Aviation (now part of Boeing) in the late-Forties. The aircraft – the first western jet to feature swept wings, as well as one of the first capable of breaking the sound barrier in a dive – saw action throughout the Korean War and Cold War, and has become a highly recognisable icon in aircraft engineering history.

Built initially to combat the Russian MiG-15, the Sabre was geared towards flight superiority roles, dispatched to undertake furious high-speed dogfights. Though inferior to the Russian jet in terms of lightness and weaponry, the reduced transonic drag delivered by the swept wings – combined with its streamlined fuselage and advanced electronics – granted it far superior handling. This ability to outmanoeuvre the MiG-15 saw it establish supremacy in combat.

Despite overall armament inferiority to its rivals, the Sabre was one of the first military jets capable of firing guided air-to-air missiles and later variants, such as the F-86E, were fitted with radar and targeting systems that were revolutionary for the time. These factors, along with its high service ceiling (ie maximum altitude) and its generous range of around 1,600 kilometres (1,000 miles), therefore enabled it to intercept any enemy aircraft with ease.

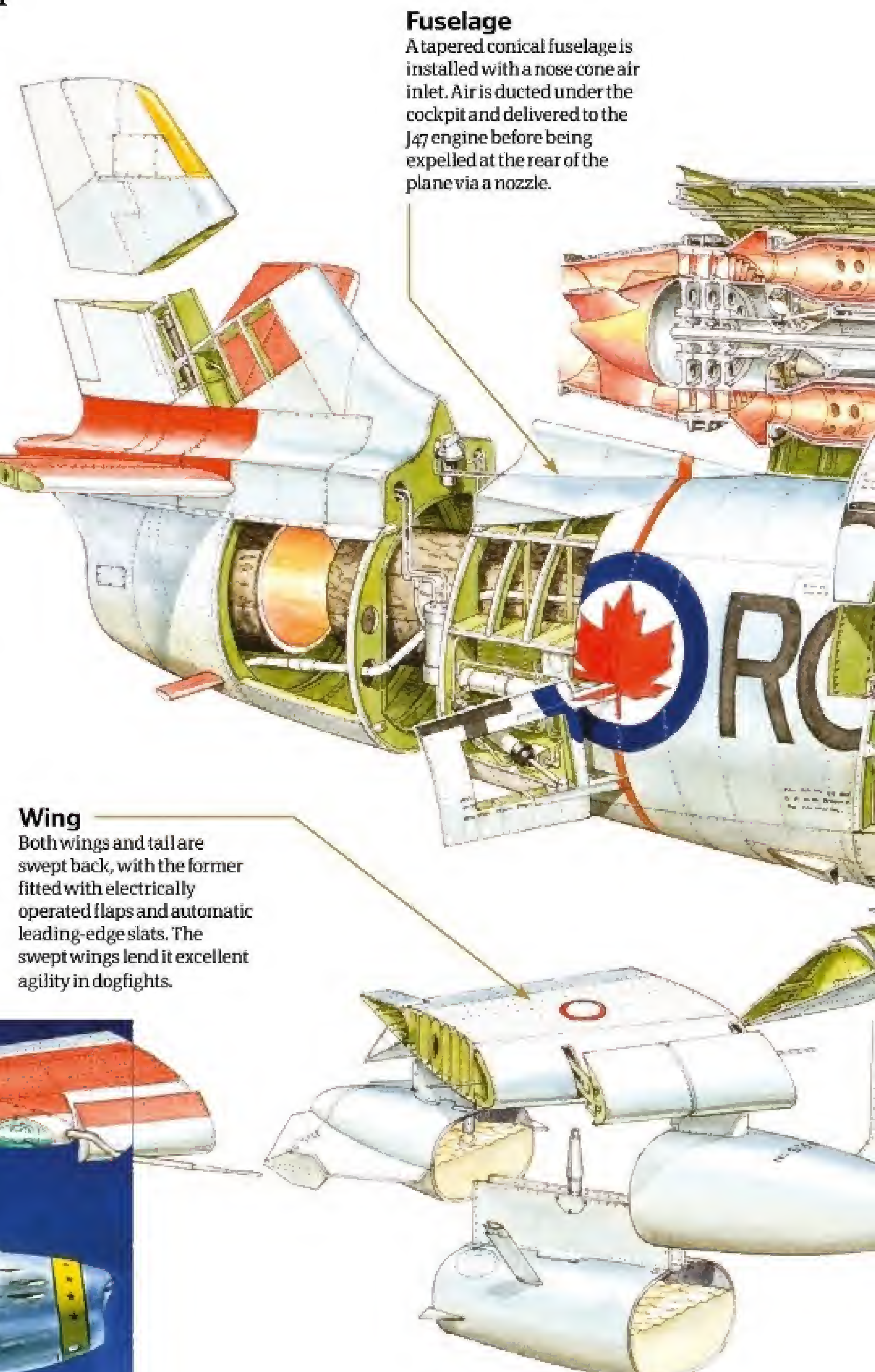
However, today the Sabre is most known for its famous world record-breaking performances, with variants of the jet setting five official speed records over a six-year period in the Forties and Fifties. Indeed, the F-86D made history in 1952 by not just setting the overall world speed record (1,123 kilometres/698 miles per hour), but then bettering it by an additional 27 kilometres (17 miles) per hour the following year. It is partly due to these records that the F-86 remains to be a beloved aircraft and will be remembered throughout history.

Today there are no F-86s that are still in service in national militaries. They have naturally been replaced by more modern and more advanced aircrafts as time went by and new technologies were developed. However, due to their iconic status and reliable handling, many remain in operation in the civilian sphere, with 50 privately owned jets registered in the US alone. They are extremely popular with collectors and aircraft enthusiasts alike, and continue to inspire the next generation of engineers to this day.

Although built in North America at least 20 other countries used Sabres in their air forces, including Japan, Spain and the UK

On board the F-86E

Explore the advanced engineering that makes the Sabre such a formidable fighter jet…



Engine
The F-86E uses a GE J47-13 turbojet engine capable of outputting 2,358kgf (5,200lbf) of thrust. This raw power grants it a top horizontal speed of about 1,050km per hour (650mph).

Cockpit
The F-86E is fitted with a small bubble canopy cockpit that covers a single-seat cabin for the pilot. The cockpit is in a very forward position, tucked just behind the nose cone.

The statistics...

F-86E Sabre

Length: 11.3m (37ft)

Wingspan: 11.3m (37ft)

Height: 4.3m (14ft)

Max speed: 1,046km/h (650mph)

Range: 1,611km (1,001mi)

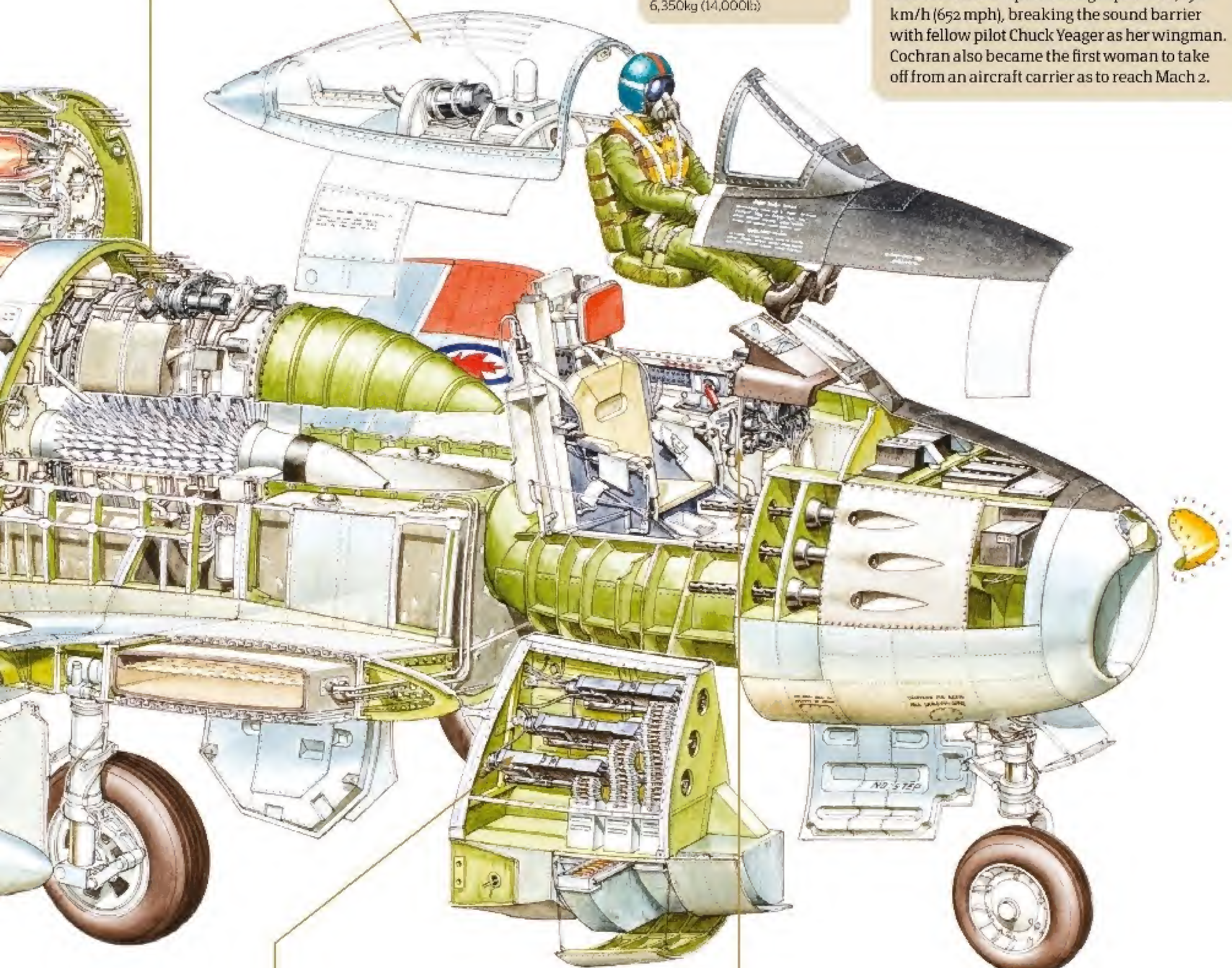
Max altitude: 1,371m (45,000ft)

Combat weight: 6,350kg (14,000lb)

Who was high flyer Jacqueline Cochran?

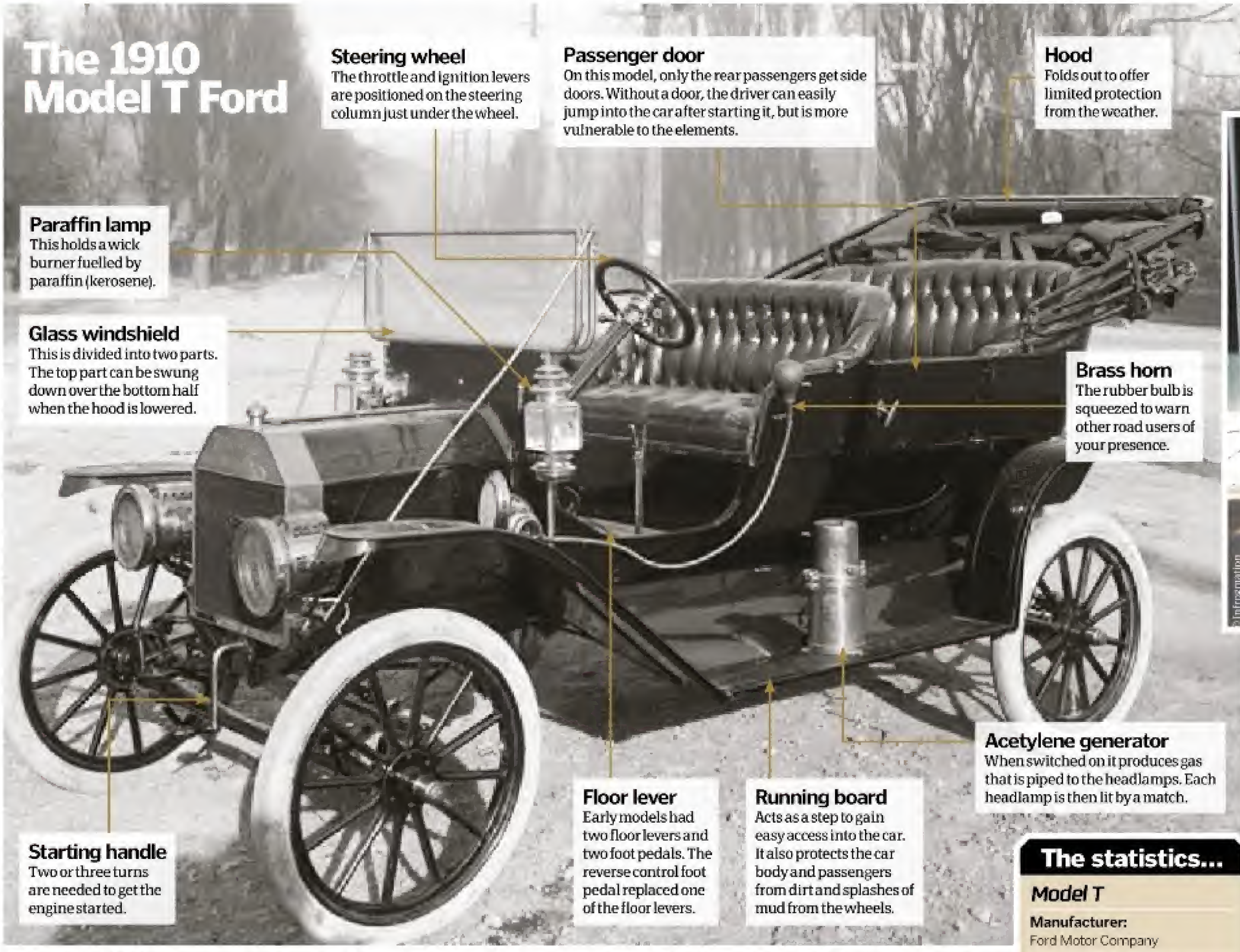
Born in 1906, Cochran was a pioneering American aviator and one of the most gifted pilots of her generation. This led her to become the first woman in the world to break the sound barrier – an amazing feat which she performed in a custom, one-off F-86 Sabre.

The record was broken on 18 May 1953 at Rogers Dry Lake in California. In her F-86, Cochran racked up an average speed of 1,050 km/h (652 mph), breaking the sound barrier with fellow pilot Chuck Yeager as her wingman. Cochran also became the first woman to take off from an aircraft carrier as to reach Mach 2.



Weaponry
The Sabre is equipped with six .50-caliber (12.7mm) M2 Browning machine guns and 16 127mm (5in) HVAR rockets, as well as a variety of freefall bombs as well as unguided missiles.

Electronics
An A-1CM gun sight in partnership with an AN/APG-30 radar system makes the F-86E one of the most technologically advanced jets of its time. The radar can quickly work out the range to potential targets.



The statistics...

Model T

Manufacturer: Ford Motor Company

Year introduced: 1908

Dimensions: Length: 2,540mm, width: 1,422mm, height: 2,387mm

Engine: 2896cc

Top speed: 45mph

Horse power: 22.5

Required fuel: Petrol

Unit price: $850

The Model T

The car that brought motoring to the masses

Early Model T styles included this popular open-top touring car

By today's standards, Henry Ford's Model T has many unusual characteristics. Before you can jump into the driver's seat, you have to turn a hand crank at the front of the car to start it. This is a hazardous process as the hand crank can break your thumb if the engine backfires, and if the throttle lever on the steering column is not set properly it will run you over as soon as it starts. Fortunately, an optional electric starter was introduced in 1919.

The Model T has three foot pedals and a floor lever. To drive off, you increase the throttle lever, move the floor lever forwards from its neutral position and depress the clutch foot pedal on the left. As you pick up speed, you can move from first to second gear by releasing pressure on the clutch pedal. To stop, drivers would simply have to reduce the throttle, press down the clutch pedal, depress the brake foot pedal on the right and put the floor lever into neutral. To go backwards you keep the floor lever in neutral and press down the middle reverse foot pedal.

Early versions of the car had brass acetylene lamps, and its ten-gallon fuel tank was mounted under the front seat. As this fed petrol to the carburettor using gravity, the Model T could not climb steep hills if the tank was low on fuel. The solution to this was to drive up hill in reverse.

Its engine is front mounted, and features four cylinders in one en bloc casting. This simple engine is relatively

Just as its modern counterparts developed different styles and shapes over the years, so too did the Model T

ON THE MAP

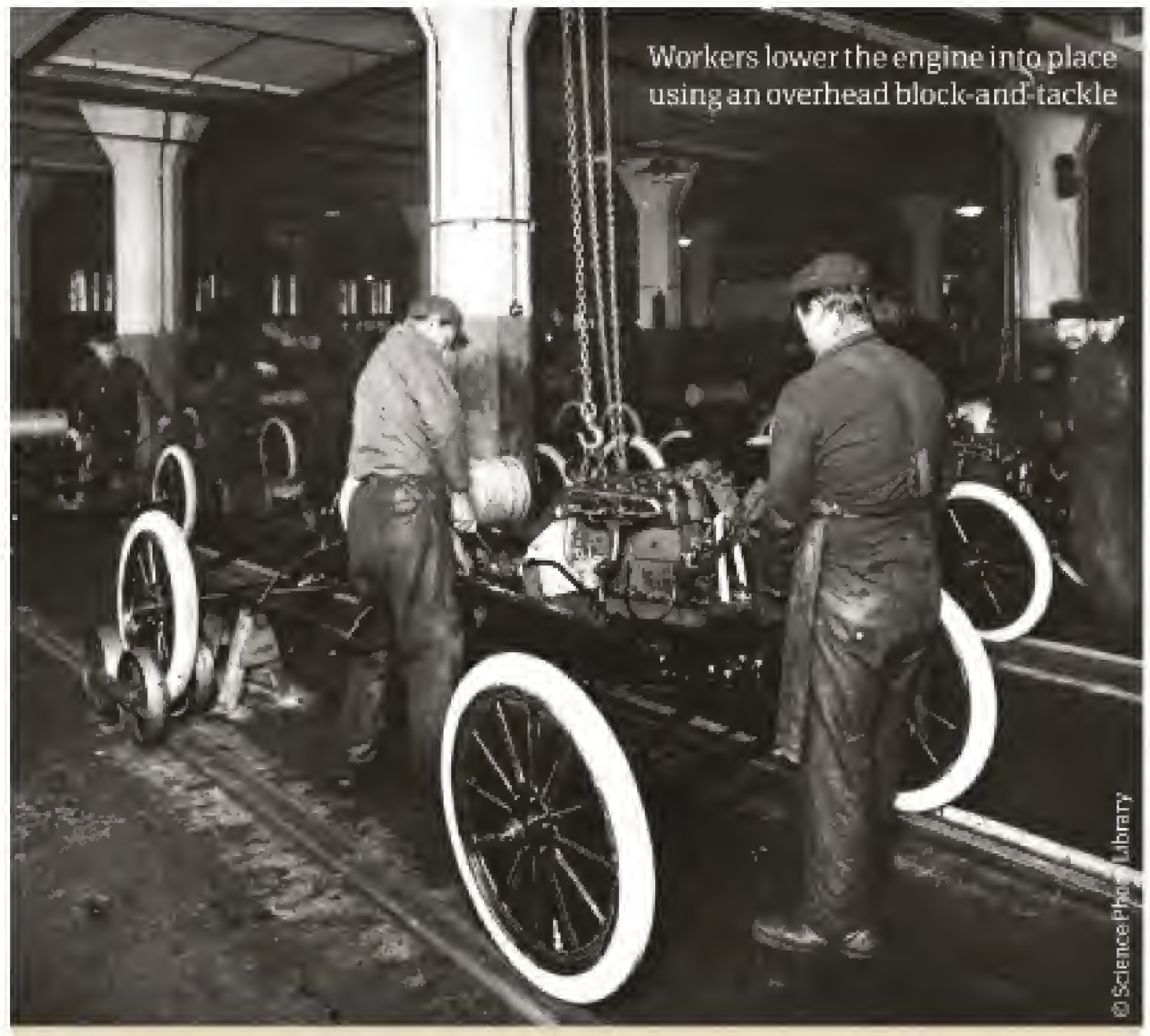
Model T production centres

1. Highland Park Plant, Michigan
2. Trafford Park, Manchester, UK
3. Walkerville, Ontario, Canada
4. La Boca, Buenos Aires, Argentina
5. Geelong, Victoria, Australia
6. Berlin, Germany

The Model T was a welcome addition to police forces

easy to run and maintain. The first models were runabouts with open bodies and a hood that can be folded down. Lots of different car and truck bodies were later fitted to the Model T chassis by Ford and other companies.

Since the Model T was equally at home in town or as an off-road farm workhorse, and available at the cheapest price possible, it quickly dominated the USA and made motoring an essential part of our lives.



Workers lower the engine into place using an overhead block-and-tackle

Mass production

The revolutionary methods used by Ford opened up a world of possibilities

Mass production using a moving assembly line was the key innovation that made the Model T so successful. Car production had been largely pitched at the luxury market with hand-built bespoke models being the norm. Henry Leland, who worked for Cadillac, pioneered the standardisation of car components, and moving production lines were used in Chicago slaughterhouses. The genius of Ford was to integrate these methods and reduce the production of the Model T to 84 key areas.

The chassis of the car was run along a track and each worker carried out a very simple and repetitive production task, before it was moved on to the next work area. The engine and other components were made in a similar manner before being added to the chassis. This slavish process made it possible to reduce the time to make one Model T from 12 hours eight minutes to 93 minutes.

As early as 1914, Ford's mass production techniques produced 300,000 cars with 13,000 workers compared to the 66,350 workers at all the other car companies who only produced 280,000 cars.

From 27 September 1908 till the end of production on 26 May 1927, 15 million Model Ts were made. The Model T met and exceeded Henry Ford's vision of creating a simply designed car using the best materials at a price affordable to everyone.

Connecting the barrel-shaped petrol tank

The Flying Scotsman locomotive

Inside the film star, record-breaker and national treasure

The original 4472 A1 locomotive was designed by Sir Herbert Nigel Gresley

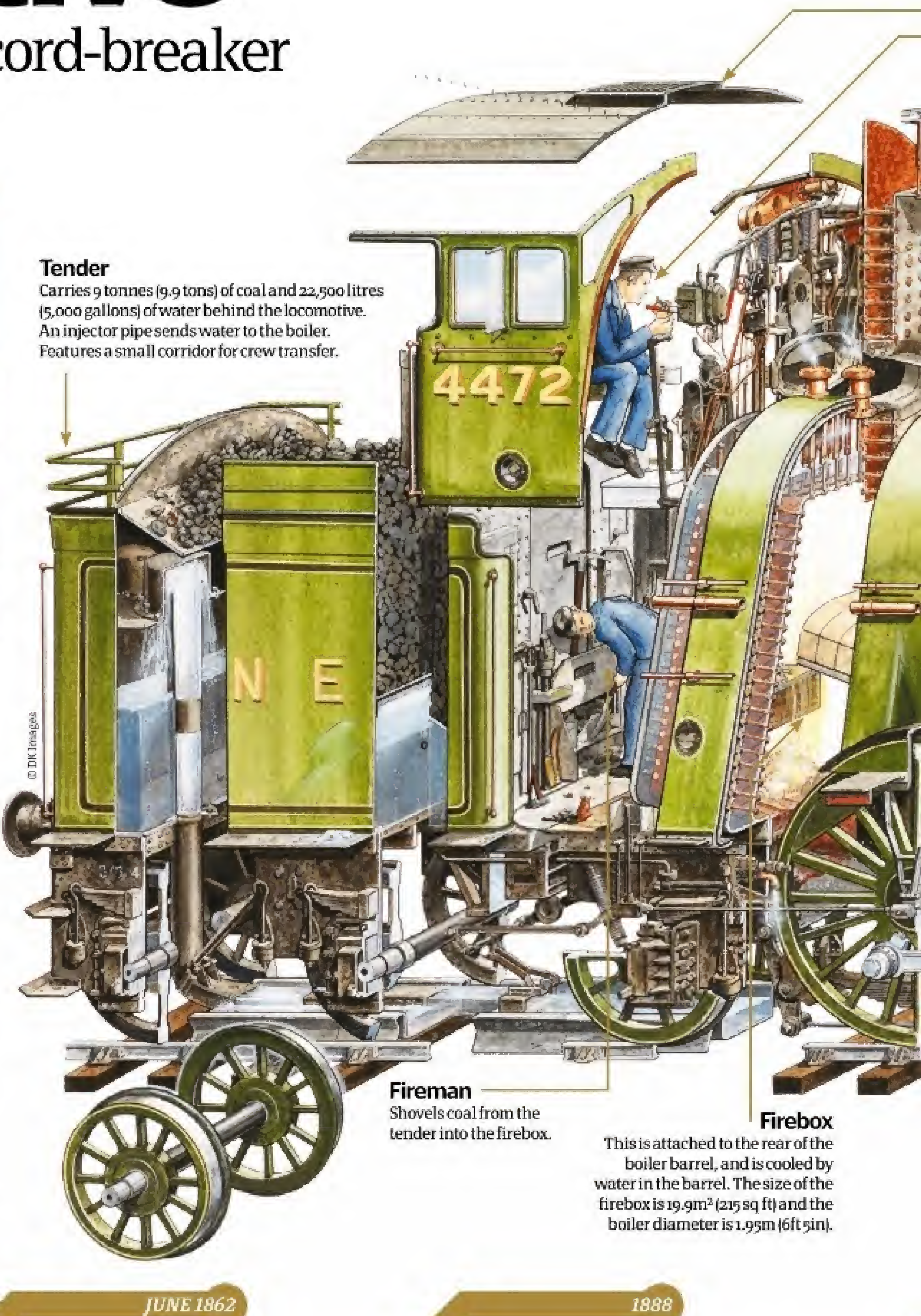
The Flying Scotsman began life as No 1472, an A1 Pacific-class locomotive. The Pacific class had a 2-6-2 arrangement of wheels, which enabled it to carry a bigger boiler, making it suitable for long-distance passenger services. Under ownership of the London and North Eastern Railway Company (LNER) it was renumbered the 4472 and christened the Flying Scotsman.

When it broke down and was taken out of regular service it was the ideal candidate for putting on show at the British Empire Exhibition in 1924 and 1925. It was an immediate hit with the public, and its fame was sealed when in 1928 it launched the regular 10am non-stop Flying Scotsman Express Service from King's Cross, London, to Waverley, Edinburgh.

To cope with the 631km (392-mile) route the locomotive pulled a special eight-wheel tender that carried great quantities of water and coal. Since the crew had to be replaced during the eight-hour journey without stopping, a special corridor was built in the tender to allow the relief crew to pass between the train and the cab.

The Flying Scotsman became even more famous on 30 November 1934, when it travelled at 160.9km/h (100mph) breaking the world speed record.

In January 1947, the Flying Scotsman was converted to the A3 class that incorporated a larger boiler with a higher boiler pressure and, a year later, it was re-designated as the No 60103 under the ownership of British Rail. In 1963, it was sold off and went through several owners before being rescued by the National Railway Museum, York, in May 2004.



© DK Images

Tender
Carries 9 tonnes (9.9 tons) of coal and 22,500 litres (5,000 gallons) of water behind the locomotive. An injector pipe sends water to the boiler. Features a small corridor for crew transfer.

Fireman
Shovels coal from the tender into the firebox.

Firebox
This is attached to the rear of the boiler barrel, and is cooled by water in the barrel. The size of the firebox is 19.9m² (215 sq ft) and the boiler diameter is 1.95m (6ft 5in).

The Flying Scotsman Express Service

JUNE 1862

Service begins
The East Coast mainline from London to Edinburgh is used to run the first Special Scotch Express, departing at 10am with a journey time of ten and a half hours.

1888

Faster
Rivalry between rail companies brought the journey time to as low as seven and a half hours. As this racing was dangerous it is agreed to set the time at eight hours 15 minutes.

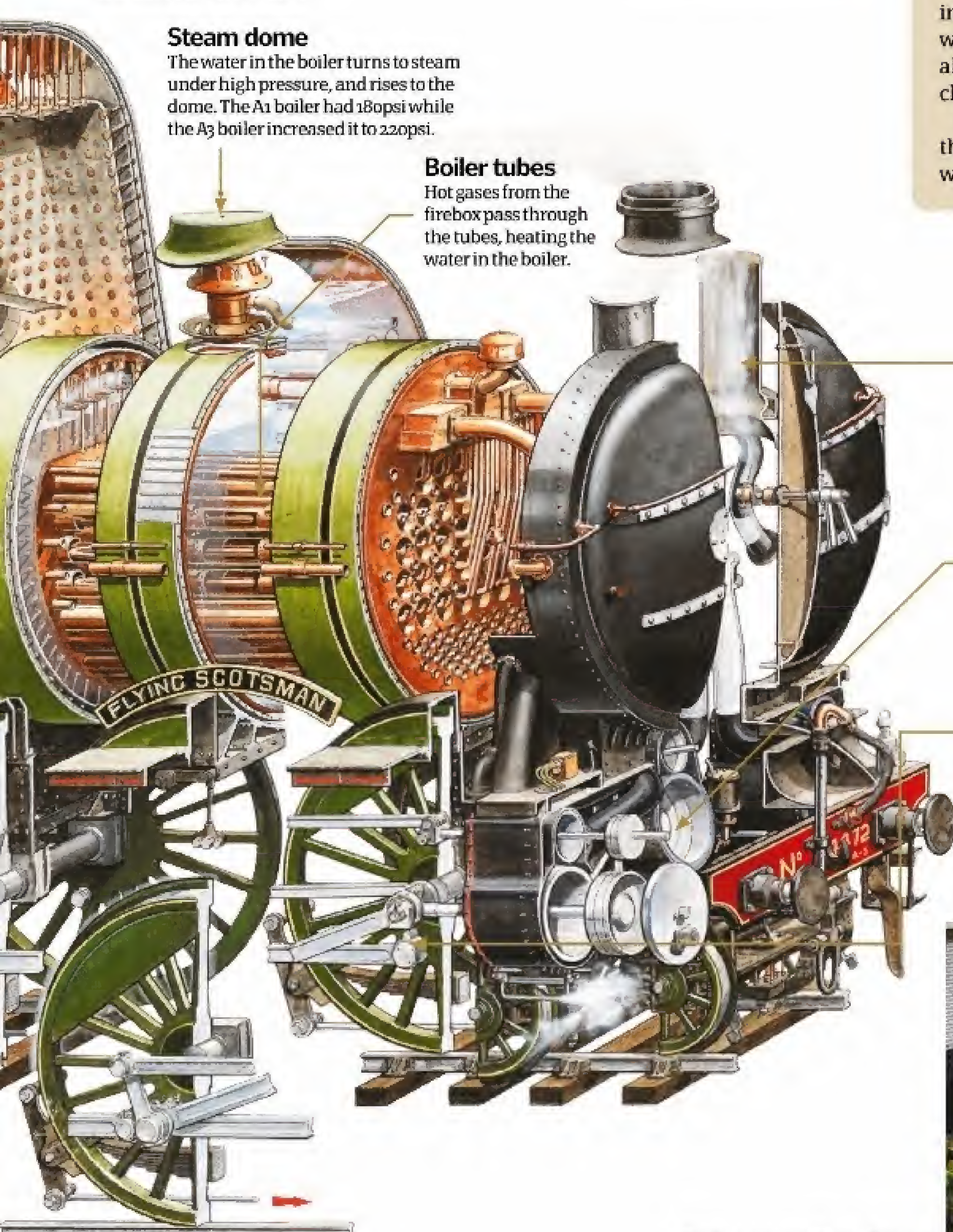
Streamlining
Since the engine was so tall, the cab, dome and chimney had to be virtually flush with the boiler to avoid hitting bridges between Newcastle and Edinburgh.

Driver
The driver uses the throttle to control the regulator in the steam dome to increase or decrease the amount of steam sent to the cylinders.

The Flying Scotsman was not only known for speed but luxury too

Steam dome
The water in the boiler turns to steam under high pressure, and rises to the dome. The A1 boiler had 180psi while the A3 boiler increased it to 220psi.

Boiler tubes
Hot gases from the firebox pass through the tubes, heating the water in the boiler.



Chimney
In 1958, the Scotsman was fitted with a Kylchap exhaust system that evenly mixed the steam from the pistons and gases from the boiler tubes to improve performance.

Cylinders
The Scotsman has three cylinders on each side. A Gresley-conjugated valve gear system orders the operation of the pistons inside the cylinders.

Cranks and connecting rods
The movement of the pistons is transferred through these rods to the wheels. The diameter of the wheels is 0.96m (3ft 2in) for the first four, 2.03m (6ft 8in) for the coupled set and for the trailing wheels 1.12m (3ft 8in).

Sir Nigel Gresley and the LNER

Herbert Nigel Gresley (19 June 1876-5 April 1941) served his apprenticeship at Crewe Locomotive Works. His leadership and engineering skills led him to become the chief mechanical engineer of the London and North Eastern Railway Company (LNER) based in Doncaster.

He designed the A1, and upgraded them to the A3 class. In 1935, he introduced the A4 class that included the Mallard, which gained the world speed record by travelling at 202.7km/h (126mph) in 1938. He also worked on steering gear for ships and, in total, designed 27 classes of steam locomotive.

Gresley was always eager to test new innovations and incorporate the best ideas from Europe and America into his designs. In 1936 he was knighted by King Edward VIII in recognition of his industry.

The statistics...

The Flying Scotsman

Designer: Sir Herbert Nigel Gresley
Manufacturer: Doncaster Railway Works
Year built: 1923
Class: A3
Length: 21.6m (70ft)
Width: 2.8m (9ft 3in)
Height: 4m (13ft)
Weight: 97.5 tonnes (107 tons)
Boiler pressure: 220psi
Top commercial speed: 108km/h (67mph)
Top record speed: 160.9km/h (100mph)
Status: Owned by the National Railway Museum, York

The London and North Eastern Railway Company is to thank for the Scotsman name

1900

Luxury
Passenger comfort is enhanced by the introduction of dining cars, heating and corridors linking carriages.

1924

Official recognition
This service had been nicknamed the Flying Scotsman since the 1870s. LNER now officially gives the service this name and gives the 4472 locomotive the same title.

1932

Speeding
The restricted journey time of eight hours 15 minutes was officially reduced to seven and a half hours.

23 MAY 2011

A new beginning
The Class 91, electric locomotive 91101 starts an Edinburgh to London weekday service. It takes just four hours to run the route.

The Mayflower

Discover what life was like on board the ship that took the Pilgrim Fathers to America

The Mayflower is one of the most famous ships associated with English maritime history. After transporting the Pilgrim Fathers to a new life in America during 1620, the Mayflower was often regarded as a symbol of religious freedom in the United States.

Originally, however, the Mayflower was a simple cargo ship that was used for the transportation of mundane goods – namely timber, clothing and wine. While statistical details of the ship have been lost, when scholars look at other merchant ships of this period they estimate that it may have weighed up to 182,000 kilograms. It is suggested that the ship would have been around seven metres wide and 30 metres in length.

The ship's crew lived on the upper decks. All in all, 26 men are believed to have manned the Mayflower on her legendary journey. The Master or Commander was a man called Christopher Jones: he occupied the quarters situated at the stern of the ship. The regular crew lived in a room called the forecastle, which was found in the bow – accommodation was cramped, unhygienic and highly uncomfortable. It was constantly drenched by sea water and the officers on board were fortunate in that they had their accommodation in the middle of the ship.

During the historic voyage, the Mayflower carried 102 men, women and children – these Pilgrims were boarded in the cargo area of the ship, which was deep below deck where the living conditions led to seasickness and disease. The Mayflower set sail from England in the July of 1620, but the ship was forced to turn back twice because a vessel that accompanied it began to leak water. Many problems affected the Mayflower and her crew during the voyage. There were serious threats from pirates, but it was storm damage that was to prove problematic on this journey. In the middle part of the expedition, severe weather caused damage to the wooden beam that supported the ship's frame. Fortunately, however, it was repairable.

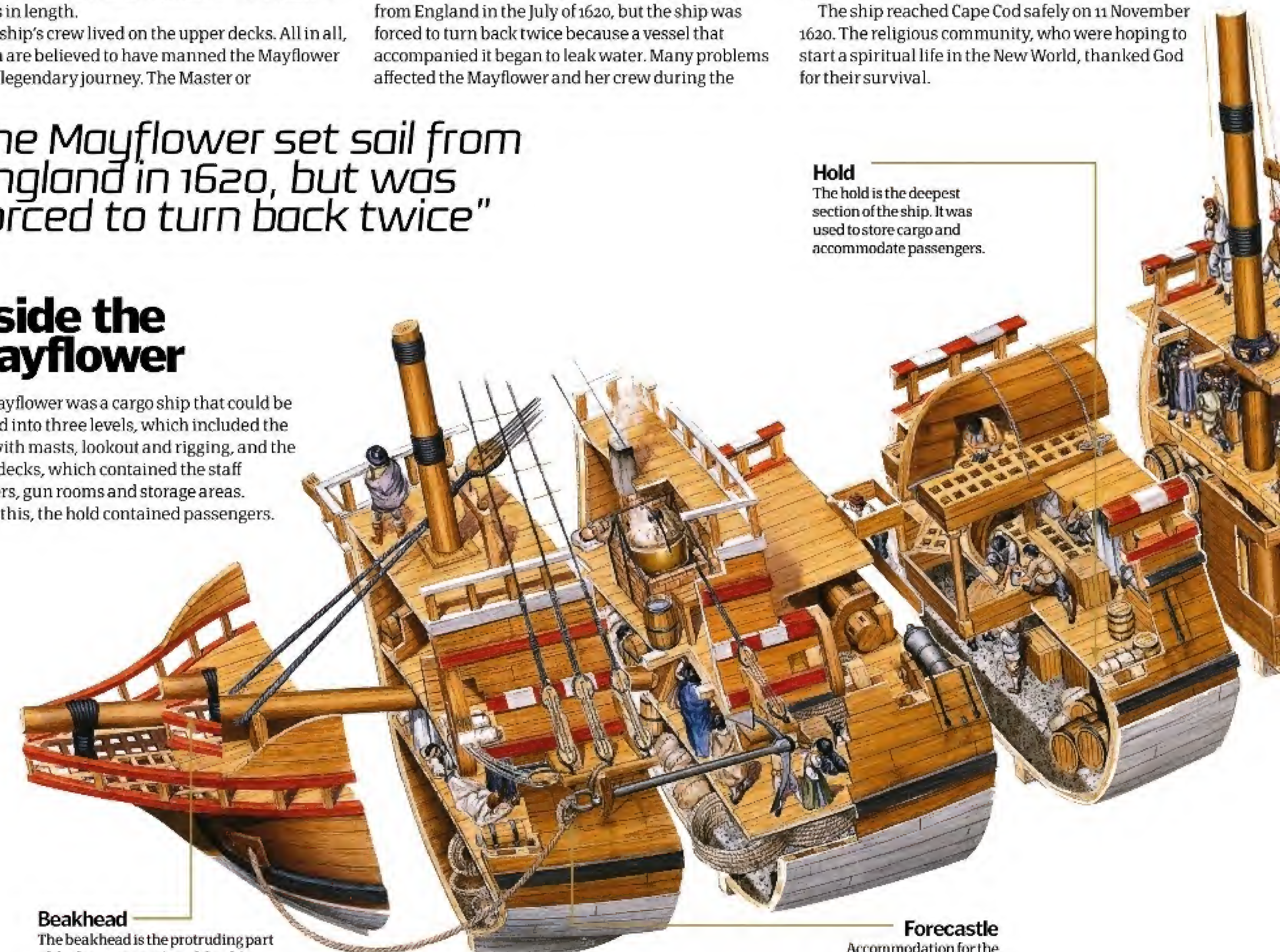
Several accidents also occurred, including the near drowning of John Howland who was swept overboard but then rescued. Less fortunate was a crew member who died unexpectedly – considered by all as 'mean spirited' – his demise was viewed as a punishment from God. A child was also born during the voyage: Elizabeth Hopkins called her son Oceanus.

The ship reached Cape Cod safely on 11 November 1620. The religious community, who were hoping to start a spiritual life in the New World, thanked God for their survival.

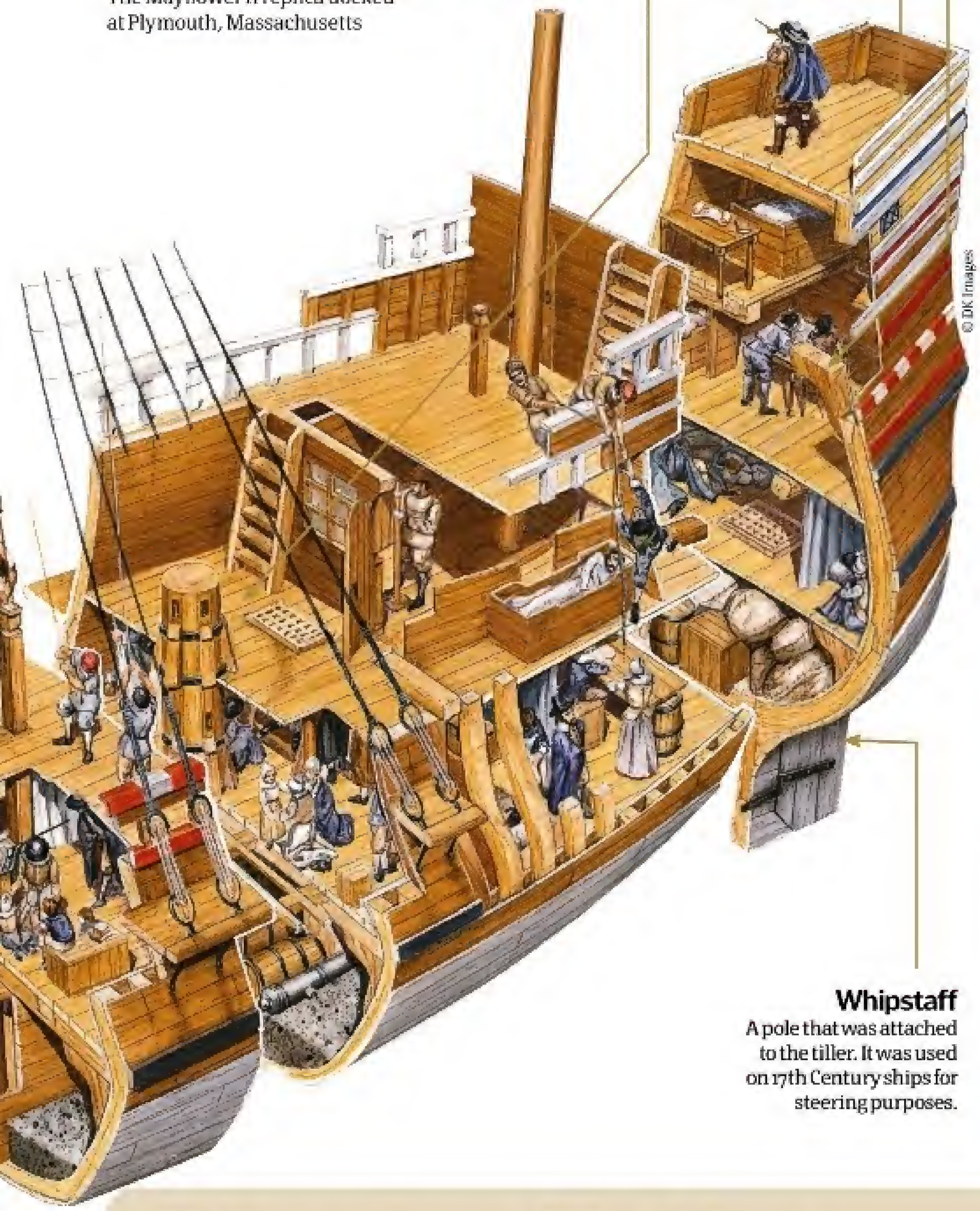
"The Mayflower set sail from England in 1620, but was forced to turn back twice"

Inside the Mayflower

The Mayflower was a cargo ship that could be divided into three levels, which included the deck with masts, lookout and rigging, and the lower decks, which contained the staff quarters, gun rooms and storage areas. Below this, the hold contained passengers.



The Mayflower II replica docked at Plymouth, Massachusetts



The Mayflower arrived at the internal fish hook of Cape Cod

Pilgrim Fathers

In 1620 a group of puritans arrived on the Mayflower destined for the New World. They were known as the Pilgrim Fathers. The Pilgrim Fathers were disillusioned with the ungodly and hedonistic behaviour of their native Englishmen and believed that America was a land of opportunity where they could start a new religious community. They landed in a place that would come to be called New Plymouth, where they began to build houses, but it is believed that half their population died during the first year of occupation. The New World was seen as a dazzling land and a second Garden of Eden, but in reality the environment was harsh and unforgiving. Some natives were helpful and taught the settlers how to survive this wilderness, and in 1621 they produced their first successful harvest. This was celebrated with the first Thanksgiving – in turn, this became a traditional feast day – and it is still observed as an American national holiday.

HMS Victory

One of the most famous ships of all time, HMS Victory was instrumental in ensuring British naval supremacy during the late 18th and early 19th centuries

The only surviving warship to have fought in the American War of Independence, the French Revolutionary War and the Napoleonic wars, the HMS Victory is one of the most famous ships ever to be built. An imposing first rate ship of the line – line warfare is characterised by two lines of opposing vessels attempting to outmanoeuvre each other in order to bring their broadside cannons into best range and angle – the Victory was an oceanic behemoth, fitted with three massive gundecks, 104 multiple-ton cannons, a cavernous magazine and a crew of over 800. It was a vessel capable of blowing even the largest enemy vessels out of the water with magnificent ferocity and range, while also outrunning and outmanoeuvring other aggressors.

Historically, it was also to be Vice-Admiral Horatio Lord Nelson's flagship during the epic naval battle off the Cape of Trafalgar, where it partook in the last great line-based conflict of the age, one in which it helped to grant Nelson a decisive victory over the French and Spanish but at the cost of his own life.

Turner's famous painting of the Battle of Trafalgar in which the HMS Victory is shown in the midst of battle

The statistics...

HMS Victory

Class: First rate ship of the line
Displacement: 3,500 tons
Length: 227ft
Beam: 51ft
Draught: 28ft
Propulsion: Sails – 5,440m²
Speed: 9 knots (17km/h)
Armament: 104 guns
Complement: 800

Sails
The HMS Victory is a fully rigged ship, with three sets of square sails covering 5,440m². The breadth of the Victory's sails allowed it to sport a maximum top speed of nine knots when operational, which was for the time very impressive considering its size and weight. During the 18th and 19th centuries a fully rigged ship necessitated three or more masts each of which with square rigging. At full flight the Victory could spread a maximum of 37 sails at one time and could carry 23 spares.

Crew
There were over 800 people on board the HMS Victory, including gunners, marines, warrant officers and powder monkeys among many others. Life on board was hard for the sailors, who were paid very little for their services and received poor food and little water. Disease was rife too, and punishments for drunkenness, fighting, desertion and mutiny ranged from flogging to hanging.

Masts

The HMS Victory sported a bowsprit (the pole extending beyond the ship's head), fore mast, main mast, mizzen mast and main yard. A total of 26 miles (41.9km) of cordage, as well as 768 elm and ash blocks, were used to rig the ship.

Decks

The HMS Victory had seven main decks, including: the hold, orlop, lower gundeck, middle gundeck, upper gundeck, quarterdeck and poop deck.

(A) The hull
The hull was the largest storage area on the ship where up to six months of food and drink could be stored, as well as any excess supplies.

(B) The orlop
The only other deck below the waterline, the orlop was another storage area and also habitation deck for certain crew members such as the purser.

(C) The gundecks
Housed the majority of the Victory's cannons, with a tiered arrangement from top to bottom (largest cannons on the bottom, smallest on the top). These decks also housed the majority of the crew and Royal Marines, sleeping in hammocks suspended from battens fixed to overhead beams. The lower gundeck also acted as mess deck, the space where the crew would live and eat.

(D) The quarterdeck
The nerve centre of the ship, where its commander dictated its manoeuvres and actions often under heavy gunfire from rival vessels.

(E) The poop deck
Located at the stern, this short deck takes its name from the Latin word puppis, which literally means 'after deck' or 'rear deck'. This deck was mainly used for signalling, but also gave some protection to the man helming the ship's wheel.

Cannons

As a first rate ship of the line, the Victory was a three-gundeck warship with over 100 guns. In fact, the Victory was fitted with 104 cannons: 30 x 2.75 ton long pattern 32-pounders on the gundeck, 28 x 2.5 ton long 12-pounders on the middle gundeck, 30 x 1.7 ton short 12-pounders on the upper gundeck, 12 x 1.7 ton short 12-pounders on the quarterdeck, and 2 x medium 12-pounders and 2 x 68-pounder carronades on the forecastle.

Bathyscaphe Trieste

A real-life Nautilus, the Bathyscaphe Trieste explored the deepest parts of Earth's oceans, remaining to this day one of the only manned vehicles to have reached the bottom of the Mariana Trench in the Pacific

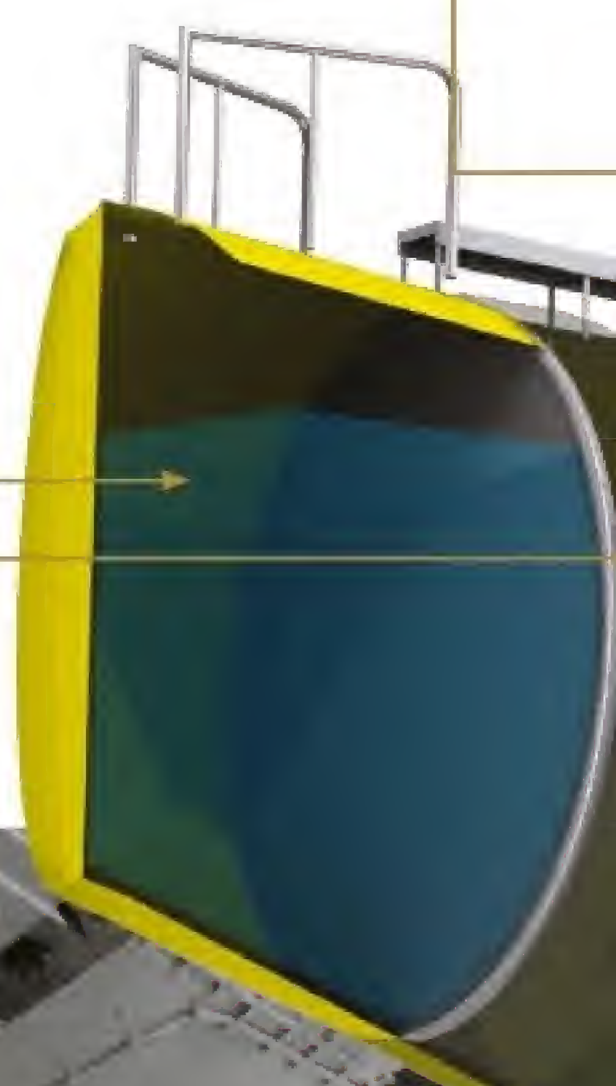
After passing 9,000 metres (30,000 feet), one of the Plexiglas windows cracked. Over 1,000 atmospheres – a pressure over six tons per square inch – relentlessly bore down upon the Bathyscaphe Trieste. The hull shook violently, threatening to collapse under the mighty strain. If fractured on even a microscopic scale, the weight of the Earth's deepest ocean would rip the vessel in two, triggering explosive decompression and instantly killing both oceanographer Jacques Piccard and pilot Lieutenant Don Walsh of the US Navy. 23 January 1960, however, was not their day to die. The men had still not reached the bottom of the Mariana Trench's Challenger Deep; the structure *had* to hold – there was no plan B.

Descending further into the black void, completely cut off from the outside world – the sonar/hydrophone communications system had packed up hours ago – the Trieste continued to dump iron pellets into its ballast system. After all, you don't descend vertically nine kilometres (nearly six miles) beneath the surface of the ocean only to quit so close to your goal. Then finally, out of nowhere and after four hours and 48 minutes within a two-metre (seven-foot) pressurised sphere, Piccard, Walsh and the Trieste touched down. Clouds of diatomaceous ooze (made of the skeletons of dead sea-creatures) diffused from the seabed on contact, filling the surrounding water with a liquidated organic haze.

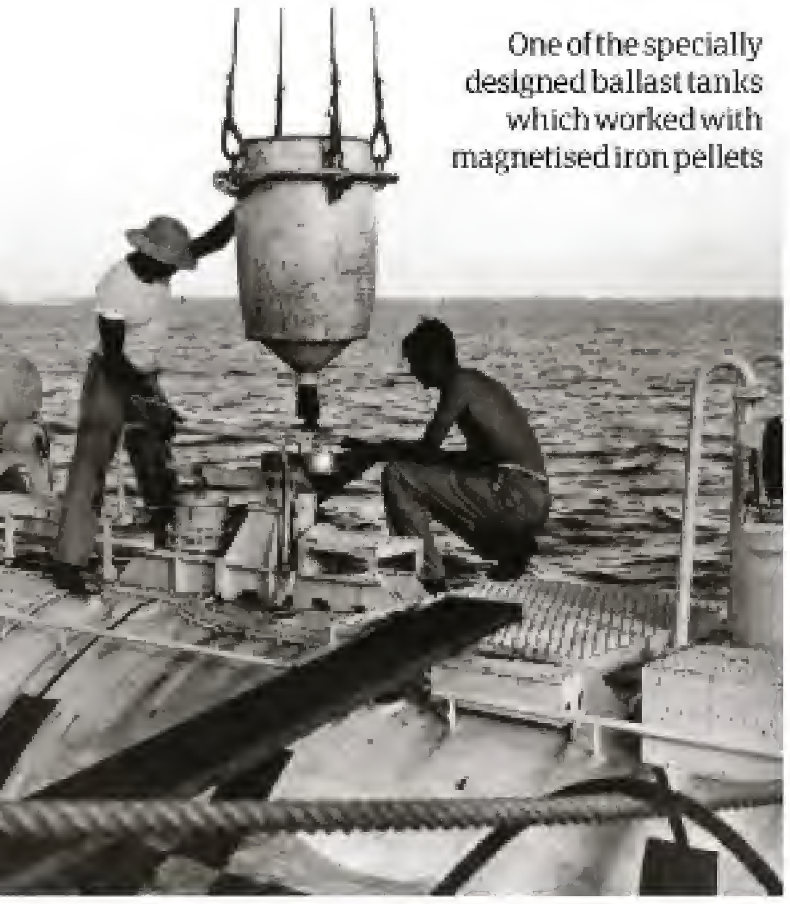
Half an hour later, after periodically observing this alien environment with high-powered quartz arc-light lamps – periodically as when activated they caused the water to violently boil – and discovering a multitude of life including a white flatfish, several shrimp and jellyfish, Piccard initiated the Trieste's ascent. The vessel had held, but at a depth of 10,916 metres (35,814 feet) the temperature of the pressure sphere was dropping continuously (the minimum recorded was just seven degrees Celsius/45 degrees Fahrenheit); if they were not careful, there would be no return. Three hours and 15 minutes later, the Trieste re-emerged into the daylight and human civilisation. The vessel and its crew had been to a world only envisioned in fiction and returned with field-changing information.

Key to the data gathered was establishing the existence of life at the bottom of Earth's deepest ocean. This revealed that not only were there creatures impervious to extreme atmospheric pressures, but also that water at this depth wasn't stagnant. This was a clear indication that ocean currents even penetrated these extreme depths, so they should not be used as a dumping ground for radioactive waste. Unfortunately, despite this first-hand evidence, dumping of this kind still continues throughout large parts of the world to this day.

Today the legacy of the Trieste is being built upon, with numerous programmes currently underway focused on designing new vehicles to return to this uncharted territory. The most high profile of these is Richard Branson's Virgin Oceanic, which intends to return to the bottom of the Mariana Trench in the near future.


A close-up view of the Trieste's pressure sphere, clearly showing the Plexiglas observation window and instrument leads

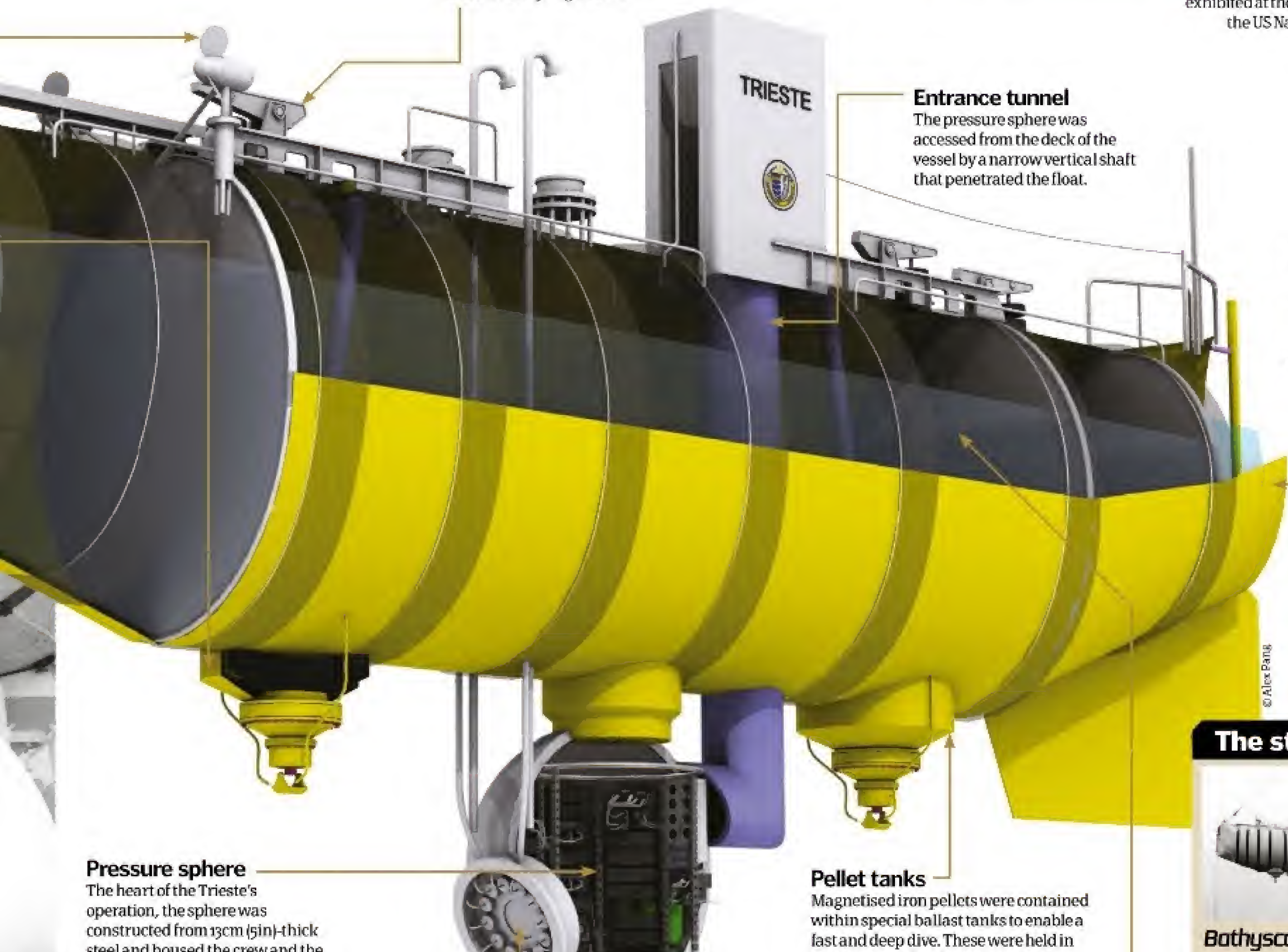


One of the specially designed ballast tanks which worked with magnetised iron pellets

Inside the Bathyscaphe Trieste

We take a look at the machinery and technology that enabled this record-breaking dive

The Bathyscaphe Trieste is now exhibited at the National Museum of the US Navy in Washington DC



Electromagnets

The magnetic iron pellets that allowed the Trieste to descend so deep were held in place actively by large electromagnets. As such, if there was an electrical failure, the vessel would automatically begin to rise.

Entrance tunnel

The pressure sphere was accessed from the deck of the vessel by a narrow vertical shaft that penetrated the float.

Hull

The Trieste's hull was made from steel and held numerous ballast tanks. The pressure sphere that contained the vessel's crew was mounted centrally to its belly.

Pressure sphere

The heart of the Trieste's operation, the sphere was constructed from 13cm (5in)-thick steel and housed the crew and the vessel's instrumentation.

Observation window

The only transparent material on the entire craft, the observation window was made from a cone-shaped block of shatterproof Plexiglas (acrylic glass).

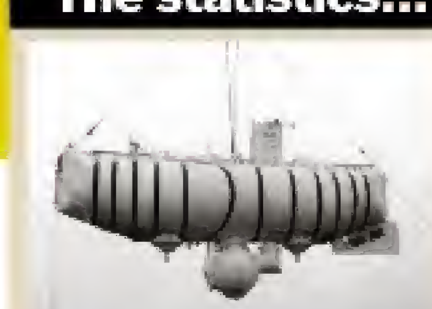
Pellet tanks

Magnetised iron pellets were contained within special ballast tanks to enable a fast and deep dive. These were held in an active state by electromagnets.

Gasoline tanks

Due to the extreme weight of the pressure sphere, large gasoline-filled tanks were used to ensure neutral buoyancy. Gasoline was chosen as it is relatively incompressible at extreme pressures.

The statistics…



Bathyscaphe Trieste

Type: Bathyscaphe

Crew: 2

Displacement: 51 tons

Length: 18.1m (59.6ft)

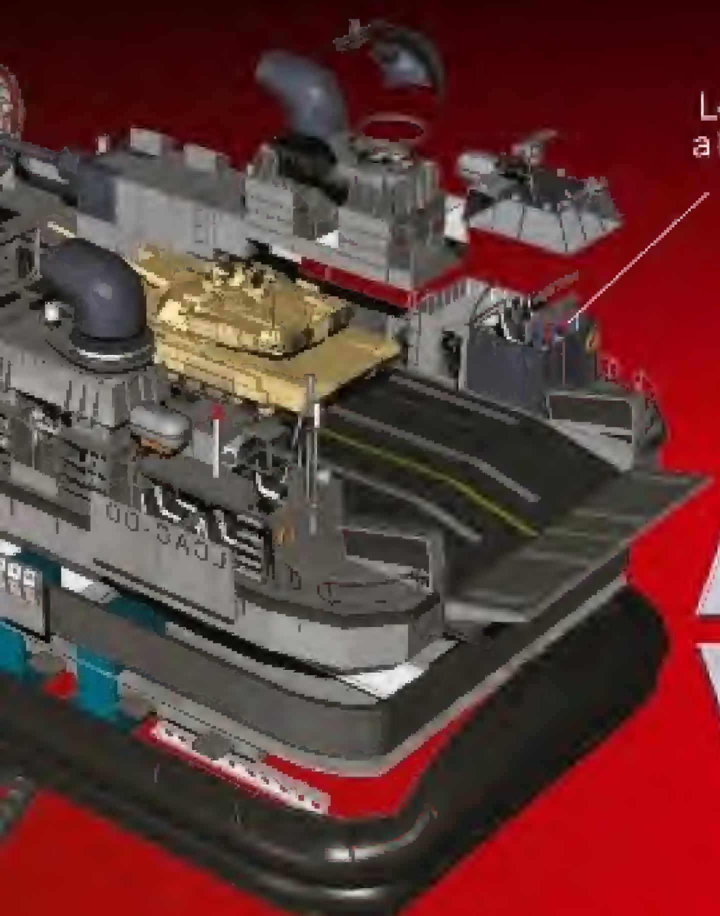
Beam: 3.5m (11.6ft)

Draft: 5.6m (18.6ft)

FUTURE

FUTURE

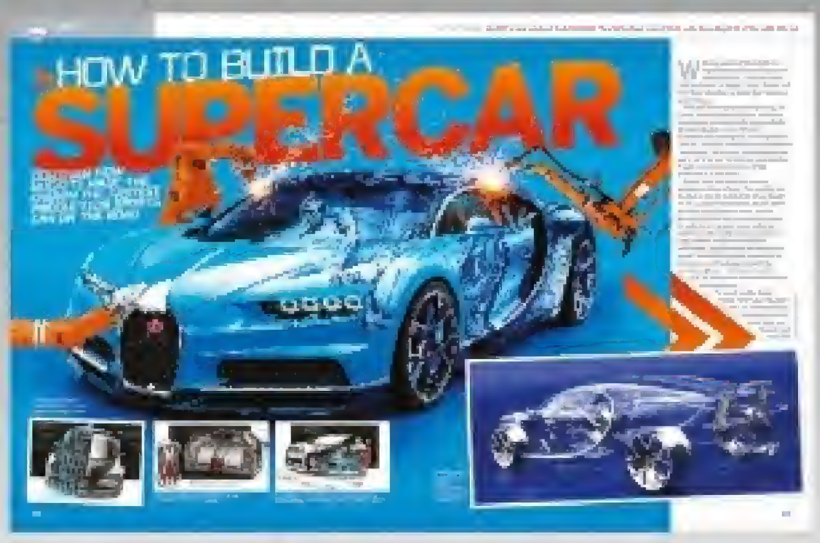
HOW IT WORKS BOOK OF AMAZING VEHICLES



Look inside a hovercraft

Discover hi-tech spy planes

A LOOK INSIDE SOME OF THE WORLD'S MOST INCREDIBLE MACHINES



LAND

See how technological advances made our cars, bikes and trains faster and more energy efficient than ever

AIR

Take to the skies and discover the incredible aircraft that are breaking records and soaring to new heights

SEA

Learn about the amazing vessels that traverse the seven seas and dive to the depths of the oceans

The most advanced machinery

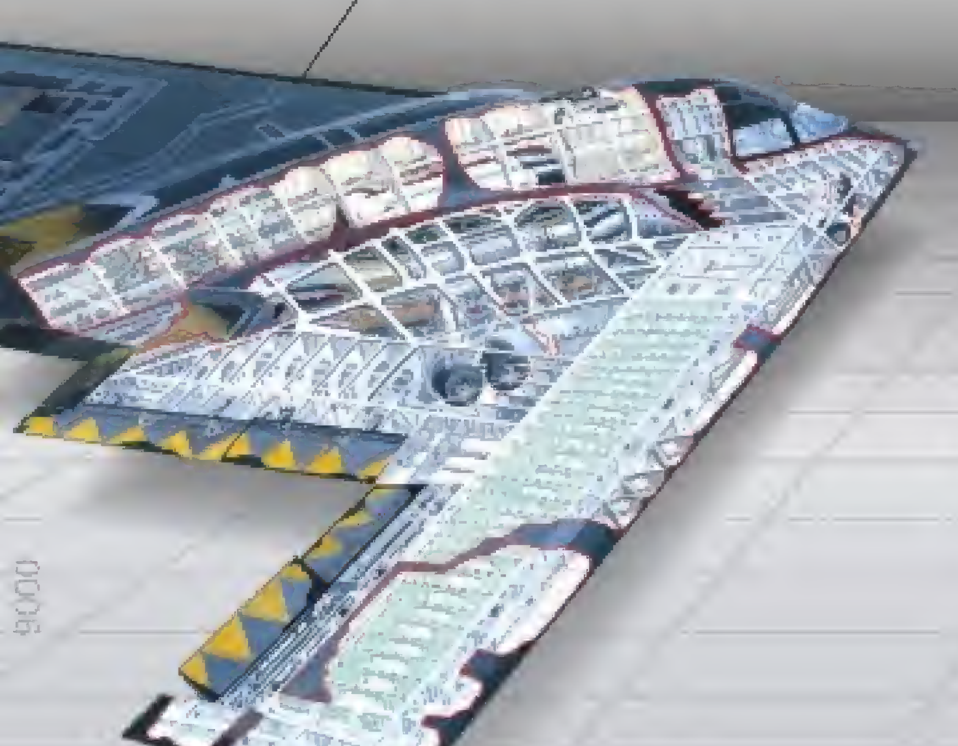
MILITARY

Find out how new methods, materials and machines are changing the face of modern warfare

HISTORIC

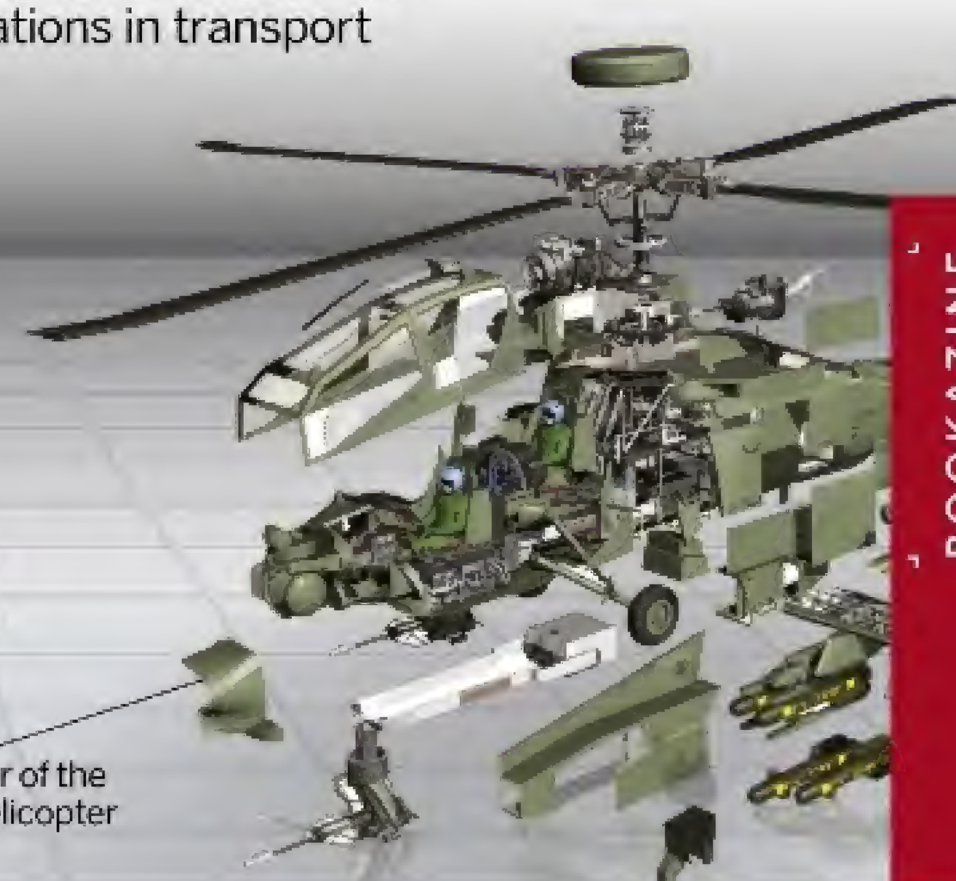
From the Mayflower to the Ford Model T, uncover some of the most iconic innovations in transport

Deep sea explorers



Examine the B-2 Stealth Bomber

The world's deadliest vehicles



The power of the Apache helicopter

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